

The AMSAT[®] Journal

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CONTENTS

**MOST: A Space Astronomy
Microsatellite Mission.....1**

By Robert E. Zee, et.al.

Apogee View.....3

By Bill Tynan, W3XO

**Understanding AO-10's
Hibernations.....13**

By Stacey E. Mills, W4SM

**Observed Radiation Effects
on KitSat-1.....16**

By Chris Jackson, G7UPN

**Field Ops Update: Lessons
Learned from the Fleamarket
Front.....17**

By Barry Baines, WD4ASW

Grass Roots on the Grass....18

By Dee Interdonato, NB2F

**Remote Sensings of the
Ionosphere Using Satellite
Radio Beacon
Observations.....19**

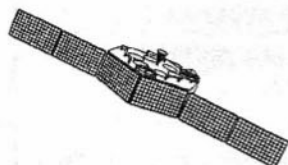
*By Frank Bauregger and
Christine Law*

ESA Meeting Held.....23

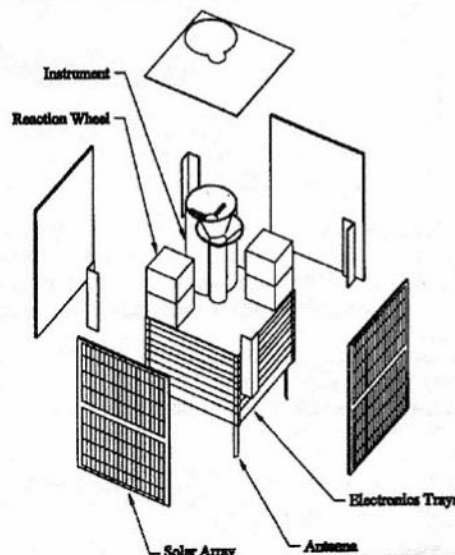
**Minutes of the AMSAT Board
of Director's Meeting Held
October 19 and 20, 1997 in
Toronto, Ontario Canada.....24**

Satellite Orbital Elements.....27

By Ray Hoad, WA5QDC



Support Phase 3D!



MOST Microsat Layout

MOST: A Space Astronomy Microsatellite Mission

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Professor Jaymie Matthews, University of British Columbia
Slavek Rucinski, Canada-France-Hawaii Telescope
Robert E. Zee, University of Toronto

The MOST (Microvariability and Oscillations of STars) astronomy mission has been chosen by the Canadian Space Agency's Small Payloads Program as a candidate for Canada's first space science microsatellite. This paper provides a summary of the scientific objectives of MOST, and describes a mission and satellite system architecture designed to achieve those objectives. The level of attitude control system (ACS) performance required by the mission is challenging to achieve using a microsatellite platform; an analysis is presented of a high performance attitude control system design that meets these requirements. In addition, the role of AMSAT is described together with the benefits to the Amateur Radio community.

[continued on page 4]

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Apogee View

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their talents, time, and efforts to produce The AMSAT Journal.

What's been going on? by Bill Tynan W3XO

My *Apogee View* appearing in the November/December issue of *The AMSAT Journal* summarized the status of Phase 3D, including the financial side. This will serve to update the information presented at that time and discuss some other activities. The good news is that the structural modifications to the spaceframe have been completed and the electronic modules on hand have all been re-installed. Plans are being made to conduct the full integration in advance of conducting thermal vacuum and vibrations testing. It has been decided to redesign the mounts which support the spacecraft in the SBS. A design is now complete and, following approval by Phase 3D Project Leader, Dr Karl Meinzer DJ4ZC, fabrication will begin soon. In general, this can proceed in parallel with integration of the spacecraft and its testing.

As I am writing this, there is nothing new to say with respect to a launch. But, rest assured, Karl Meinzer is doing everything possible in his negotiations with ESA officials to obtain an early launch for Phase 3D. Of course, AMSAT News Service (ANS) will carry breaking information as soon as something concrete can be said. So, keep watching the weekly ANS bulletins.

The fundraising letter sent to AMSAT members in late November, was quite successful and we all owe a deep debt of thanks to those who responded. As of this writing, about \$50,000 has been received from this appeal. This is much better than some predicted, especially being the last of so many fundraisings. But, of course, it falls far short of the \$270,000 stated as being needed for AMSAT to break even on Phase 3D. That amount could be raised if just half of our members would contribute \$100 each. So, if you didn't respond, it's not too late. And your help is still very much needed.

Speaking of fundraising, I just picked up the next group of plaques which will be sent in recognition of the dedication of pieces of Phase 3D hardware to people who have donated a minimum of \$2,500. Some of these are going to those who completed that amount during this latest fundraising drive. Others will receive smaller, individually inscribed, plaques attesting to contributions from \$1,000 to \$2,500. So, as I said, "It's not too late." You too can have a row of solar cells, or another

piece of Phase 3D hardware dedicated to you and receive one of these attractive plaques. Remember, all of your previous Phase 3D contributions, made directly through AMSAT-NA, count toward your total. So, you may not have to come up with \$2,500 to qualify. The same goes for the special smaller plaques which will be awarded to everyone contributing the required amount directly through AMSAT-NA.

In the meantime, other things have been going on. As some of you know, I have been striving for ways to be able to fund keeping the Orlando facility open once Phase 3D is completed. Since I don't believe the amateur community will be ready, willing and able to contribute to some new satellite project almost as soon as Phase 3D is off the launch pad, I have been looking at other sources of money to tide us over until the next project. My feeling has been, and continues to be, that if we can do some work for other groups, possibly even commercial groups, we can keep the Orlando Lab, and more important, its people, available when, and if, we do want to mount another amateur satellite project in a few years. This is one reason I attended the Small Satellite Conference in Logan, Utah last September. While there, I met several people who showed interest in working with AMSAT on satellite projects. One was a group from the University of Toronto Institute for Aerospace Studies (UTIAS) which was preparing a proposal to the Canadian Space Agency for a small spacecraft to carry a telescope to measure the variations in brightness of particular stars. The project is called MOST, which stands for **M**icrovariability and **O**scillations of **S**Tars. Once the Toronto people became familiar with AMSAT and its heritage, and heard that our Annual Meeting and Space Symposium was to be held in their city only a month hence, they became very interested. They even presented a paper on MOST at our Symposium. This led to the AMSAT Board authorizing Robin Haighton VE3FRH VP for Canadian Liaison, to enter into discussions with the UTIAS people. This, in turn, led to an offer on their part to include an Amateur Radio package on the MOST spacecraft and to provide AMSAT with a substantial donation of money in exchange for our

participation in the project, provided they get the go-ahead from the Canadian government. That, of course is not certain as there are three other groups, with different missions, vying for the same funds. UTIAS also asked AMSAT to participate in a review of the MOST proposal prior to its submission, December 31st, and agreed to pay all of the AMSAT people's expenses. This was arranged for the weekend of December 13 and 14 in Toronto. Representing AMSAT were Jan King, W3GEY, Tom Clark W3IWI, Lou McFadin W5DID, Mark Kanawati N4TPY, Dino Lorenzini KC4YMG, Robin Haighton VE3FRH and me. They were a very intense two days and all of the AMSAT people made valuable suggestions for improving the MOST design. But, more importantly, they agreed that the proposal represents a credible approach. In addition, many pieces of information were supplied by AMSAT folks following the two day session. This included valuable battery, and other satellite construction information, provided by David Liberman, XE1TU.

So, December was quite busy with arranging the Toronto trip, the weekend itself and many follow-up letters and memos in support of the MOST proposal. Now, all we can do is wait and see what the Canadian government decides. If the MOST project gets the nod, and the funding, we will enter into detailed negotiations regarding our specific roles and how AMSAT will be rewarded for its participation. But, before any final agreement is signed, the AMSAT Board will have to give its stamp of approval. AMSAT's participation in MOST appears to be in our best interest, as well as those working on the project. And, once the MOST spacecraft in orbit, it should also provide an additional amateur communications facility; the details of which are yet to be worked out. See the feature article on MOST which appears in this Journal issue.

Not wanting to put all of our eggs in one basket, I continue to look for other sources of revenue with which to support the Orlando facility and other worthwhile AMSAT activities, until we decide on future projects. My strong feeling is, that with the presence of the Orlando Lab and its people, we have a lot more options as to what we can do in both the immediate and more distant future, than we will if we close down that facility and attempt to store the equipment that has been amassed there.

As always, opinions from you, our members, are welcome on this, and other, subjects. ■

[MOST continued from page 1]

The primary objective of the MOST mission is to conduct long-duration stellar photometry observations in space. These data will be analyzed by astroseismologists, to determine precisely the vibration frequencies of the characteristic modes of oscillation of the targeted stars; these, in turn, can be used to provide estimates of stellar ages, and of the composition of stellar interiors (it may also be possible to directly observe the presence of planets around the target stars in the photometry data). These analyses require very long-duration (one to two months) sequences of observations to allow the requisite accuracy to be achieved in estimating oscillation frequencies. Due to the day/night cycle, as well as the vagaries of weather, it is very difficult to collect data runs of this duration using Earth-based telescopes; in addition, for telescopes on the Earth, atmospheric turbulence degrades the photometry data enough to make the frequency analysis difficult or impossible to achieve.

A space-based telescope is an ideal platform from which to conduct these observations. There exist several families of low Earth orbits from which many stars can be viewed continuously for 8 weeks or longer, and observations from space will not be subject to the degrading effects of observations taken through the atmosphere. A very small-aperture telescope (under 15 cm) is sufficient to conduct photometry for most visible stars; this type of instrument is compatible with the payload size, mass, power and data handling capacity of many microsatellite missions that have been flown.

A mission concept has been developed for MOST, using a 780 km dawn/dusk, sun-synchronous orbit to achieve continuous viewing of near-equatorial stars for durations of up to 8 weeks. The science payload is a small telescope with a CCD array to collect photometry data, with a pointing accuracy requirement of about 1 arc-minute. This is supported by a satellite bus whose design is based on that of commercially available microsat buses; however, the current state of the art for microsat attitude control can only achieve about 1 degree of pointing accuracy, typically by using a gravity gradient boom, magnetometers and magnetorquers. The MOST mission baselines a High-Performance Attitude Control (HPAC) system employing the science instrument as a star sensor, plus angular rate sensors, magnetometers, reaction wheels and magnetorquers to achieve the

pointing requirements. A combination of commercially-available and custom developed ACS components has been identified to implement this design. A series of performance analyses, using a detailed attitude dynamics and control simulator, has confirmed that this design can meet the mission's ACS requirements; some results of these analyses are presented here.

MOST and the CSA Small Payloads Program

In 1996, the Space Science Branch of the Canadian Space Agency initiated the Small Payloads Program (SPP) with an Announcement of Opportunity. (Available on the World Wide Web at http://www.dan.sp-agency.ca/www/spp_a0/a0.html.) The CSA has in the past supported missions employing balloon- and sounding-rocket-based science payloads, and the SPP extends this to include microsatellite-based missions. Based on its approved funding level, the SPP plans to launch one Canadian space science microsat mission every 3 years; these will be the first dedicated Canadian space science satellites since the Alouette and ISIS ionospheric topside sounding missions of the 1960s. The SPP will support missions within the three priority areas of the Canadian space science program:

- Space Astronomy
- Solar-Terrestrial Physics
- Atmospheric Studies

The MOST mission is one of four that have been selected by the SPP for detailed evaluation. Phase A studies are complete for each of these missions and only one of these is to be chosen for development in late February 1998.

MOST is a space astronomy mission. It employs a microsatellite platform to support a very small astronomical telescope, which collects light from target stars for measurement by an *imaging photometer*, a very sensitive CCD array which can measure the brightness of the target stars, and the change in their brightness over time. Unlike telescopes whose purpose is to generate star-field images, a photometer does not require a highly-focused image; this allows a useful photometry mission to be carried out using a small-aperture telescope. The limited

light-gathering power of the small telescope results in a low star-image signal intensity; this is compensated by conducting very long-duration observations of each target star, and correlating the resulting data records in order to recover an acceptable signal/noise ratio. In this way, MOST has found a way to conduct fundamentally important observational astronomy using a very small, inexpensive satellite.

The Space Systems Engineering Group at the University of Toronto Institute for Aerospace Studies (UTIAS) is assuming a lead role in designing and constructing the satellite. Team members at the university will consist of a full-time, dedicated staff along with graduate students participating through microsat courses and/or theses. Currently, Dr. Robert E. Zee (UTIAS) and Dr. Kieran A. Carroll (Dynacon Enterprises Limited) supervise a microsat design project course, the results of which contributed to the MOST Phase A study. Dynacon Enterprises Limited, of Toronto, is collaborating with UTIAS, and will provide management and oversee systems design, attitude control systems (ACS), and integration and test.

The Principal Science Investigator for the MOST mission is Professor Jaymie Matthews, of the Department of Physics and Astronomy at the University of British Columbia. Co-investigators include Slavek Rucinski (Canada-France-Hawaii Telescope), Professor Anthony Moffat (Université de Montréal), and Dimitar Sasselov (Harvard-Smithsonian Center for Astrophysics). The science team is developing the mission's detailed science requirements, as well as developing the design for the MOST telescope instrument, with the assistance of the Ontario Centre for Research in Earth and Space Technologies.

Of all the features of the SPP, one of the most significant is the requirement that all missions be conducted at a very low cost. At the lower end of the price range for recent commercial microsatellite missions, this constraint has a primary effect on the approach taken in specifying the mission's science objectives, as well as on the instrument and bus design solution to meet those objectives. Meeting this challenge is possible for MOST because of a propitious combination of circumstances:

- There is also a good match between the type of orbit that MOST needs in order to carry out the necessary long-duration stellar observations, and the likely availability of secondary payload launch opportunities to these orbits. MOST requires a level of attitude control system performance that is considerably better than has been demonstrated on previous microsat missions. Fortunately, Dynacon has a strong expertise in the ACS area, and (with support from the CSA) has developed subsystem and component designs and design tools that have allowed a High Performance Attitude Control system to be designed that meets the MOST requirements.
- The ACS performance goal is made easier to achieve because it is possible to make use of image data from the science telescope instrument, to provide attitude reference data whose quality is an ideal match to the attitude estimation process requirements for the mission.
- The University team members have a strong interest in the MOST mission, and their support brings access to the types of additional resources and areas of expertise that have characterized other successful, low-cost microsat missions in the past.

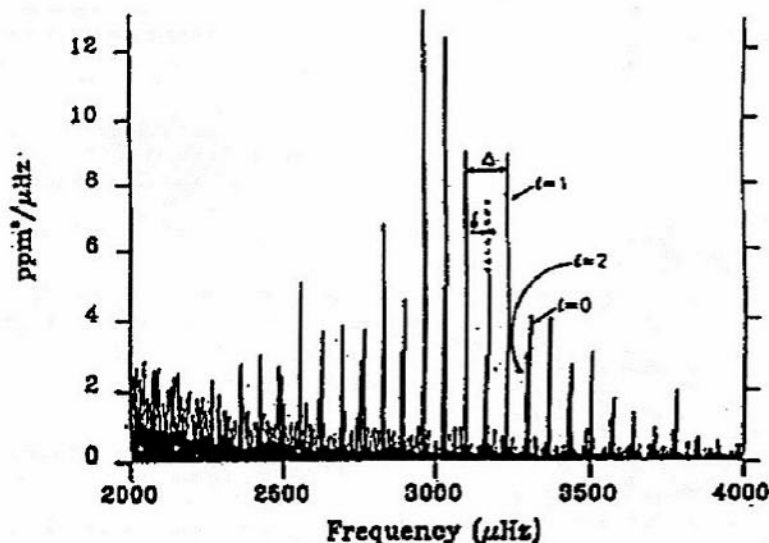
Scientific Rationale and Objectives

The Challenge: Analysis of subtle solar oscillations with periods near five minutes (caused by sound waves refracted through the solar interior by the varying sound speed of the gas) has opened a new window on the structure of our nearest star—the Sun. Using instruments such as spectrographs (which measure solar surface velocities along the Sun/Earth vector) and photometers (which measure variations of solar brightness), this young technique of *helioseismology* has confirmed the essential accuracy of the Standard Solar Model (by which we calibrate all other stellar models), and even shed light on the need for new high-energy neutrino

physics. Due to the Sun's proximity to Earth, imaging versions of these instruments can resolve oscillation patterns across the Sun's surface.

Astronomers would like to extend this technique to other Sun-like stars but have failed to make any clear detections to date. The challenge is illustrated by the case of the Sun. If the Sun's light output is integrated across its entire surface (thus emulating the way that we see a distant unresolved star), the oscillation amplitudes are only a few cm/s in radial velocity and a few micromagnitudes (on the order of 10^{-6}) in flux. In order to achieve such velocity precision using spectrographic techniques would, even for the brightest stars, require the largest telescopes and much more stable spectrographs than are currently available. In the case of photometry, photometric precision from Earth-based instruments is fundamentally limited by scintillation noise caused by our turbulent atmosphere. This can only be reduced from the ground by employing several telescopes of very large aperture over many months of time. A dedicated network of six ground-based 10-metre telescopes would be capable of seeing the five-minute oscillations in the brightest solar-type stars, but would have an estimated capital cost of US\$745M and an annual operating cost of about US\$90M.

The same goals are attainable with a single telescope of modest aperture (~15 cm) in orbit, above the scintillating atmosphere and monitoring stars in its Continuous Viewing Zone (CVZ—defined under



Fourier Power Spectrum of solar oscillations observed photometrically in integrated light with the IPHIR Photometer from Russian *Phobos* Mars Probe. Note that largest peak amplitude is <4 ppm.

- There is a good match between the basic science data-collecting objectives of this mission, and the capabilities of existing microsat bus designs to support payloads of the size, mass and power consumption required.

Mission Analysis) for weeks to months, at a fraction of the cost of a terrestrial network.

The Requirements: The sound waves propagating within the Sun set up acoustic oscillation modes at the surface corresponding to different eigenfrequencies and spherical harmonic patterns. In other stars, all but the simplest mode patterns would average out over the visible disk, but the remaining modes would appear as a *comb* of nearly equally spaced frequencies in a Fourier power spectrum. The spacing depends on the sound travel time across the star—giving us its radius—while small deviations from that spacing are sensitive to the composition of the stellar core. Since a main sequence star like the Sun is gradually converting its supply of hydrogen into helium to produce energy, the core composition is a *clock* which keeps track of the star's age. In the solar eigenmode spectrum, adjacent frequencies are spaced by about 70 μHz ; the fine structure can be as small as a few μHz . Frequency splitting due to the star's rotation can easily be as small as 0.5 μHz . Therefore, to obtain the best asteroseismic data, the necessary frequency resolution demands an observing time baseline of about 1/0.2 μHz , or about two months.

Gaps in the time series will introduce alias peaks and sidelobes in the Fourier spectrum, so the time coverage must be nearly continuous. The final photometric precision in the Fourier spectrum must be at the level of a few ppm.

The Science Return From MOST: MOST would satisfy all the data requirements at a relatively low cost. In a one-year mission, it could monitor at least six target stars and return the following results:

- First confirmed detection of Sun-like oscillations in another star (still not achieved from Earth).
- Acoustic eigenmode frequency spectra of several stars, from which we can infer stellar radii and ages to test indirect models. Our ability to model ages of stars weighs heavily on the current debate over the age of the Universe.
- Serendipitous detection of any Earth-sized planets whose orbits around the MOST target stars might cause eclipses and hence flux decreases on the order of 10 micromag.
- Accurate tracking of starspots carried around the stars' surfaces by rotation.
- Very precise eigenfrequency spectra of one or two magnetic pulsating stars (roAp stars) whose fine-splitting also contains information about internal magnetic field strength and geometry - insights which are impossible to obtain in any other way.

Mission Analysis

Planning for the MOST mission is dominated by two requirements:

- **Low Cost:** The budget constraint for the project rules out all but the least expensive of launch opportunities. These include secondary payloads on launchers such as Delta and Ariane, and Get-Away Specials on a Space Shuttle. In each of these cases, the available mass and volume allocations are small, and the choice of orbit is dictated by the primary payload. This requirement also strongly favours orbits below about 900 km altitude; above that altitude, high Van Allen belt radiation levels favour the use of expensive, rad-hardened electronic components over less-expensive, commercial-grade components.
- **Long-Duration Uninterrupted Stellar Observations:** Given a small telescope aperture, long (up to several weeks) duration observations are required in order to achieve an adequate signal/noise ratio following analysis of a star's photometry data. An uninterrupted record of observations will improve the results of the analyses. Every Earth orbit has a Continuous Viewing Zone (CVZ) centered about the two orbit normal vectors, which are cones with half-angle equal to the declination of the Earth's horizon below the satellite's local horizontal plane, as illustrated in the accompanying figure; stars located within the CVZ are visible from the satellite for the full duration of an orbit. This requirement implies that the CVZ dwell on each of the selected target stars for durations exceeding one month. This requirement is achievable only for near-polar and near-equatorial orbits.

The orbit which has been chosen as the baseline for the MOST mission meets these requirements; it has the following characteristics:

- **Sun-Synchronous:** The orbital plane, and hence the CVZs for this type of orbit precess about the celestial poles at a rate of about 1°/day, providing access to a large number of stellar targets, but with a slow enough scan rate to allow long-duration observations. The Sun always lies within about 35° of the center of one of the CVZs, while the other CVZ always points in the

anti-Sunwards direction; the MOST telescope will target stars in the latter CVZ, allowing the body of the satellite to shield the telescope's aperture from the Sun. Also, many Earth-observation satellites are launched into this type of orbit as primary payloads, creating many possible secondary payload opportunities.

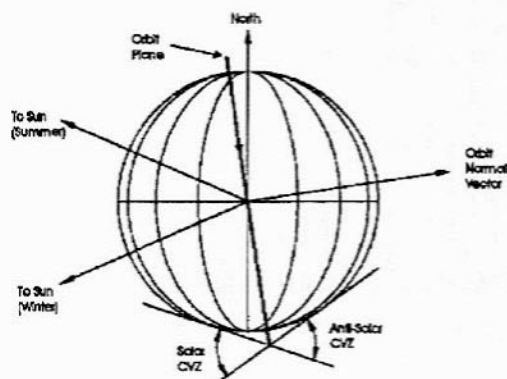
- **Baseline Altitude:** A 785 km altitude circular orbit has been baselined, equal to the altitude of Canada's Radarsat satellite (the corresponding inclination is 98.6°). This is high enough to have a large CVZ (26° half-angle), resulting in target star dwell times within the CVZ of up to 7 weeks; it is also high enough that atmospheric drag will not significantly degrade the orbit within the first year of operations. This orbit is low enough to avoid severe radiation effects from the Van Allen belts.
- **Ascending Node:** A dawn/dusk sun-synchronous orbit, with an ascending node of either 6 pm (like Radarsat) or 6 am, offers particular advantages to the satellite design. At the baseline altitude, this type of orbit does not experience eclipses for most of the year, and the maximum-duration eclipse is less than 15 minutes long (out of a 100-minute orbital period). This offers the potential to design the satellite's power subsystem with relatively small batteries, and for a relatively large fraction of solar-array power production to be available for direct use rather than for battery charging. In addition, for the ten eclipseless months of the year the satellite's thermal environment will be almost static, with one side always facing the Sun and the opposite side always facing deep space; this should simplify the thermal control system analysis and design task, helping to keep engineering costs to a minimum.
- **Attitude Control Modes:** The primary mode of the attitude control system will be to keep the boresight of the satellite's telescope aimed towards the current selected target star; it will use star-field image data from the telescope as its attitude reference during this mode. A slew mode, also using star-field image data, will be used to maneuver from one target star to the next. Other ACS modes include an initial detumbling mode (following separation from the launch vehicle), and a *safe-hold* sun-pointing mode using the Earth's magnetic field and/or the Sun as attitude references.

(Other types of orbits have also been considered and found to be able to meet the MOST mission requirements, albeit without achieving all the advantages of the baseline orbit.)

System Design

The main requirements at the mission level that must be satisfied by the MOST system include:

- Ability to point towards a series of target stars, for uninterrupted observation periods up to 2 months.



MOST orbital characteristics.

- Sufficiently small telescope field of view to allow discrimination of the target star from other nearby stars.
- Sufficiently precise attitude control to allow discrimination of the target star from other nearby stars.
- Sufficiently large telescope aperture, and sufficiently sensitive detectors, to generate a large enough signal/noise ratio for photometry measurements, in order to achieve the target value for post-analysis S/N ratio.
- Sensitivity compatible with a sufficient number of potential target stars, to ensure that at least one target star is available for observation at most times during the mission.

Target numerical values for these requirements have been developed iteratively, in conjunction with a system design that meets those requirements. The concept for the system design stems from the observation that above the Earth's atmosphere, a very small telescope instrument will be able to collect enough light to permit useful observations to be taken for many of the brightest stars. A candidate microsat system design was identified, out of several recent, successful microsat missions with costs similar to the MOST cost cap, that has demonstrated the payload volume, mass, power and data handling capacity to accommodate this size telescope for this mission. However, this telescope requires inertial-pointing accuracy of about 0.2° , and stability of about $0.02^\circ/100$ sec, and none of the microsat buses considered were able to achieve these requirements (available bus designs typically achieve about 2° Earth-pointing accuracy via gravity-gradient boom stabilization). The concept that was selected comprises three elements:

- A telescope instrument.
- A satellite bus to mount the telescope instrument on, providing power, control, pointing and data collection and communications functions.
- A ground station.

These system elements include the following major features:

- The design of the ground station, and the bus power subsystem, telecommand and telemetry subsystem, on-board data-handling subsystem, and bus structure are based on designs used in relevant microsat missions that have been flown.
- Photometry is carried out by collecting target-field images using a CCD detector using equal exposure times, and processing the images using software to sum the values of the pixels associated with the target star.
- Attitude estimation is based on data from star field images collected by the telescope instru-

ment, which automatically matches the quality of the attitude estimate to the performance level needed by the photometry image-processing software.

- Separate CCD arrays are used for the science and attitude estimation data collection, with each one being sampled at a frame rate optimized for its particular application, and for redundancy. The two CCD arrays share the same telescope optics.
- Attitude control in fine-pointing mode is achieved using a set of three reaction wheels as torque actuators, and by using magnetorquer coils to carry out angular momentum dumping maneuvers.

The operational scenario for the satellite includes the following main elements:

- Following separation from the launch vehicle, a detumbling maneuver is carried out using standard microsat techniques (e.g., B-dot control using magnetometers and magnetorquers).
- The satellite is then maneuvered so that the telescope's boresight is pointing towards the first target star. Calibration of this reference direction can be accomplished by transmitting the reference star field image to the ground station.
- The satellite points to keep the target star continually within the telescope's field of view for the desired duration of observations (up to 2 months), collecting photometry observations throughout this period.
- Photometry observation data is stored in memory on-board the satellite until a deletion command is received from the ground station. During passes over the ground station, blocks of photometry data (along with engineering telemetry data) are downloaded on command from the ground station. For the baseline dawn/dusk, sun-synchronous orbit, there are 4-6 good passes per day, with the satellite spending a total of more than 34 minutes per day at $>10^\circ$ elevation, at the CSA HQ ground station location.
- Once observations of a target star are concluded, a slew maneuver is commanded to move the telescope's boresight to point towards the next selected target star.
- If the satellite's functioning is interrupted for any reason, a safe-hold attitude mode is entered automatically, to ensure that the satellite's solar array continues to point towards the Sun, and that its antennas continue to point towards the Earth; either a Sun sensor or magnetometers could be used as an attitude reference for this mode.

Instrument Design

The main requirements of the MOST telescope instrument are:

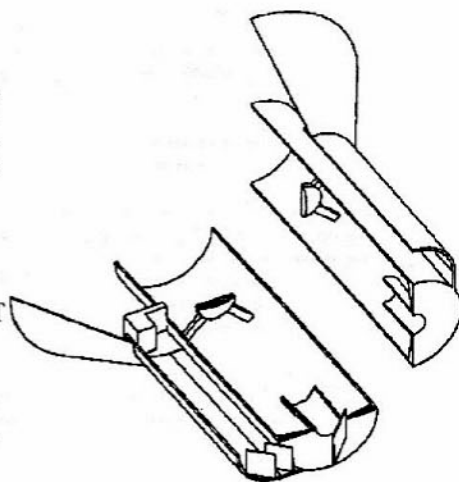
- To collect and focus light from the target star onto the science-data and star-sensor CCD detectors, while minimizing the amount of stray light from the Earth's limb onto the detectors.
- To measure images of the target star-field at a high enough rate to allow the ACS to maintain

low attitude estimation errors, with a low enough S/N ratio and calibration stability per pixel to achieve the desired level of photometric stability and accuracy, and with sufficient spatial resolution to enable sufficient (~ 1 arc-sec) star sensor accuracy and to enable the target star's photometric signal to be resolvable from that of other background stars.

- To process the measured star field images in order to measure the brightness of the target star, with the measurement interval adjustable (nominally between 1 and 100 seconds) to optimize photometric resolution for a range of target star magnitudes (i.e., using shorter measurements for brighter stars, to avoid saturating CCD pixels), using the bus's C30 DSP for processing.
- To keep instrument mass <15 kg, volume <30 liters, and power consumption <8 W.

A baseline telescope instrument design has been specified to achieve these requirements. As illustrated in the accompanying figures, the optical design uses a Cassegrainian configuration (baseline aperture 10 cm), with an effective focal length of about 200 cm, and a field of view of about 0.5° . Other features include:

- Two CCD detectors, each 1000×1000 pixels. One is used to measure science data; it is sampled at a low rate to minimize readout noise per pixel. The second is used to measure star-sensor data; it is sampled at a higher rate (baseline 1 Hz) to generate data frequently enough to meet ACS requirements.
- Each CCD is operated by its own driver electronics, which provides the interface to the MOST data-handling subsystem.
- The two CCDs and their boards are identical, providing redundancy.



MOST Instrument Layout (segmented view).

A decision regarding these options will be made during the Phase A study).

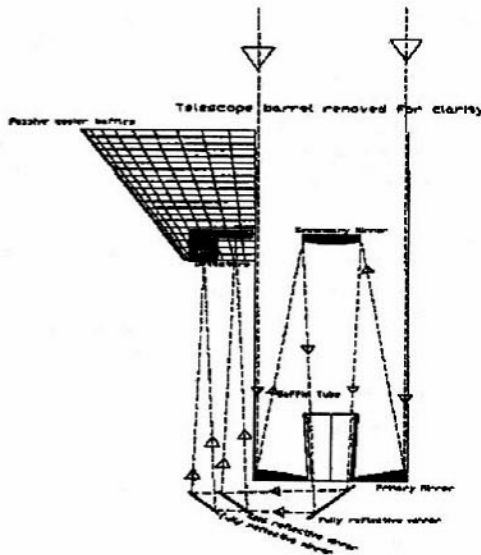
Bus Design

The main requirements for the MOST satellite bus are:

- To provide mechanical support to the telescope instrument, during launch and subsequent on-orbit operations.
- To point the telescope with sufficient accuracy (target error $<0.2^\circ$) and stability (target rate $.02^\circ/100$ sec) during photometry observation periods, and to slew from one target star to the next between observation periods.
- To process the telescope's science-CCD data to extract photometry data.
- To transmit photometry, CCD-image and engineering telemetry data to the ground when commanded (about 2 MBytes/day).
- To store these data until commands to delete them are received from the ground.

A baseline satellite bus design has been specified to achieve these requirements; the functional architecture and layout of the bus are illustrated in the accompanying figures. The bus configuration incorporates several principles that have been used in several recent successful, low-cost microsatellite missions, and is compatible with secondary payload accommodations on several types of launch vehicles. It comprises the following baseline subsystem designs:

- **Structure:** Modular aluminum trays containing electronics and other components, stacked and bolted together with the payload module at one end, and with solar arrays attached to the sides of the stack.
- **Power:** A primary solar array on the sun-facing sides generating about 40W, contingency arrays on three other sides, NiCd batteries, and power switching electronics. If the baselined sun-synchronous dawn/dusk orbit is achievable, then the satellite will be in continuous sunlight for about 10 months of each year, with maximum eclipse lengths of <15 minutes during eclipse season. Average power provision of >30 W should be possible during eclipse season, increasing to >35 W during the rest of the year.
- **Telemetry and Telecommand:** Redundant 9600 bps VHF uplink receivers, redundant 76 kbps UHF downlink transmitters, modulators, demodulators, MUXes, half-omni-directional antennas.
- **On-Board Data Handling:** 15 MIPS 80C386 on-board computer with 16 MB RAM for data collection and storage, and satellite control, plus 2 TMS320C30 DSPs for science and star sensor image processing; all equipment connected by CAN local area network, and all software uploadable in-flight.

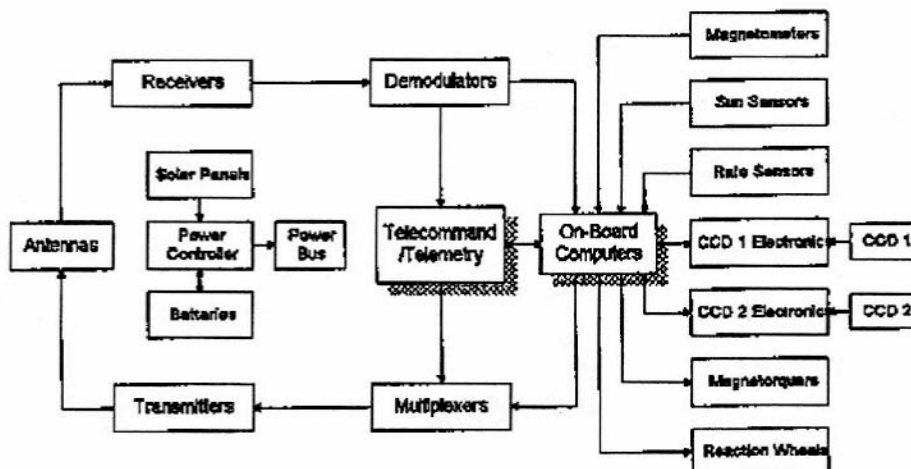


MOST Telescope Optical Path.

- Both detectors share the primary optics, with the light collected by the telescope being split by a beam splitter to service both CCDs; thus, both CCDs receive identical star-field images.
- A standard astronomical filter is included in the light path.
- The CCDs are passively cooled (baseline temperature -50°C) via mounting on a cold-plate, which radiates to space in the anti-Solar CVZ direction. A heater and temperature sensor on the cold plate are used to regulate CCD temperature (baseline is to within 1°C), to minimize temperature-dependent changes to CCD pixel outputs.
- The telescope optics are *apodized* in order to deliberately smear the image of the target star over several (baseline is 7) pixels in each direction. This is done to minimize photometric errors that would arise from a sharply-focused star image moving from the active area of a CCD pixel to the inactive mask area between pixels.
- The instrument design includes the software to be used to post-process the science-CCD image

data to extract star brightness measurements (this software will be run by one of the bus's DSP processors). The ACS is expected to produce a star-field image that wanders somewhat (baseline target is 1 arc-min, or about 33 pixels) over the course of each photometric measurement period. To compensate for this, the target star's brightness will be measured by adding up the pixel values for all the pixels within an *integrating box* centered on the target star's location at the start of imaging; the box will be large enough so that the target star will remain well within the box for the duration of each science-CCD exposure (up to 100 sec).

(Additional telescope instrument capabilities are under consideration, for example to allow photometry of multiple target stars simultaneously within the field of view, or to include additional CCD detectors with filters to allow photometry in several spectral bands.



MOST Bus Functional Architecture.

- **Attitude Control:** Attitude determination via filtered solid state rate sensors, magnetometers and telescope's star-sensor function; attitude control via 4 reaction wheels and 6 magnetorquer coils. Anticipated accuracy around 1 arc-minute.
- **Thermal Control:** Passive thermal control using MLI, thermal control coatings, stand-offs from solar arrays.

The dimensions of the bus are 33 by 33 by 53 cm, with the telescope instrument projecting about 5 cm through the *top* face of the bus module stack. The mass and average power consumption of each of the bus components is as shown in the accompanying table. The amount of power required is comfortably below the 30W expected to be available during eclipse season (as it should be at this point in the design cycle).

ACS Design Concept

The MOST system design assumes that the bus attitude control subsystem will have several operating modes available, whose requirements are as follows:

- **Detumbling Mode:** The MOST satellite is expected to be tumbling slowly after release from the launch vehicle, and may enter a tumbling state at other times in the mission due to attitude control system interruptions. The ACS shall reduce the tumble rate to a low enough value that the telescope's star sensor software is able to function, allowing a transition to fine attitude hold mode. The detumbling mode software shall be able to orient the telescope to point roughly towards the center of the anti-sunwards CVZ, and thus the primary solar array roughly towards the Sun, without employing the star sensor function, thus providing a safe-hold mode capability.
- **Fine Attitude Hold Mode:** This is the mode that will be used when carrying out photometry science observations. The orientation of the satellite shall be held steady, with the telescope field of view covering the target star for observation periods extending as long as 2 months. For individual photometry sample periods of duration up to 100 seconds, the ACS shall maintain the satellite's attitude constant to within 0.02°, to allow the science image data processing software to maintain a reasonably small sampling box around the target star.
- **Attitude Slew Mode:** After completing observations on a target star, the ACS shall (upon ground command) slew the telescope bore-sight to cover the next target star. The total slew angle may be as large as 55° (the width of the CVZ).

These are substantially more challenging requirements than those achievable by the ACS designs used in most previous microsats. A typical microsat ACS employs magnetometers that permit attitude estimation with an accuracy of about 1°, and a gravity

Bus Component	Mass (kg)	Power (W)
Mechanics and Structure	7.9	—
Power System	11.5	—
Telemetry and Command System	5.6	7.4
Attitude Determination/Control System	10.5	7.4
On-Board Data Handling System	3.1	3.5
Thermal Control System	0.5	—
Wiring Harness	1.5	—
Payload Total	7.4	3.4
Microsat Total	48.0	23.0

gradient boom that allows Earth-pointing with an accuracy of typically 5° (although accuracy down to about 1° has been demonstrated). The MOST design employs the following set of ACS components:

- Primary attitude sensing is carried out using a set of 4 *angular rate sensors*. Solid-state micro-machined sensors have been baselined, due to their low mass and power consumption. They have, however, a relatively high output noise and bias drift level. A high-rate (10 Hz) Kalman filter is applied to reduce the noise, and to propagate an estimate of the current satellite attitude.
- Secondary attitude sensing is carried out using a *star sensor*. The baseline design to carry out this function is to use software running on one of the DSPs to process image data from one of the CCDs in the telescope instrument. Each image is processed to estimate the instantaneous yaw, pitch and roll error angles with respect to the desired pointing direction. A medium-rate (1 Hz) Kalman filter combines these absolute angle error estimates with the filtered rate sensor data, allowing the rate sensors' biases to be estimated and filtered out of the overall attitude estimate.
- Further attitude sensing capability is provided by a set of redundant 3-axis *magnetometers*. Their data can either be used *raw* (in the detumbling mode, these are used to drive a B-dot type controller), or can be compared against on-board Earth magnetic field model software (driven by on-board orbit propagator software) and Kalman-filtered to provide an additional estimate of the current attitude state.
- A *Sun sensor* may be included, to provide a robust means of ensuring that detumbling mode terminates with the primary solar array Sun-facing.
- A set of 4 *reaction wheels*, oriented to align with the satellite's three primary axes, plus one redundant skew wheel, provide the primary attitude actuation capability. These are used mainly during fine attitude hold mode, which uses feedback/feed-forward control software to issue commands to the wheels to compensate for attitude errors as determined by the attitude estimation software. They are also used during slew mode, to generate the

torques needed to make the satellite track a ramping attitude set-point. They may also be used during the terminal phases of the detumbling mode, once a magnetometer-based attitude estimate becomes available, to hold the satellite attitude roughly constant.

- A set of 3 redundant *magnetorquer coil torque actuators* is included. These are used during the initial stages of detumbling mode, activated by a reflexive B-dot type controller in direct response to the magnetometer measurements, to reduce satellite rotation rates. They are also used during attitude hold and slew modes, to generate torques to desaturate the reaction wheels whenever the wheel rates approach their operational limits.

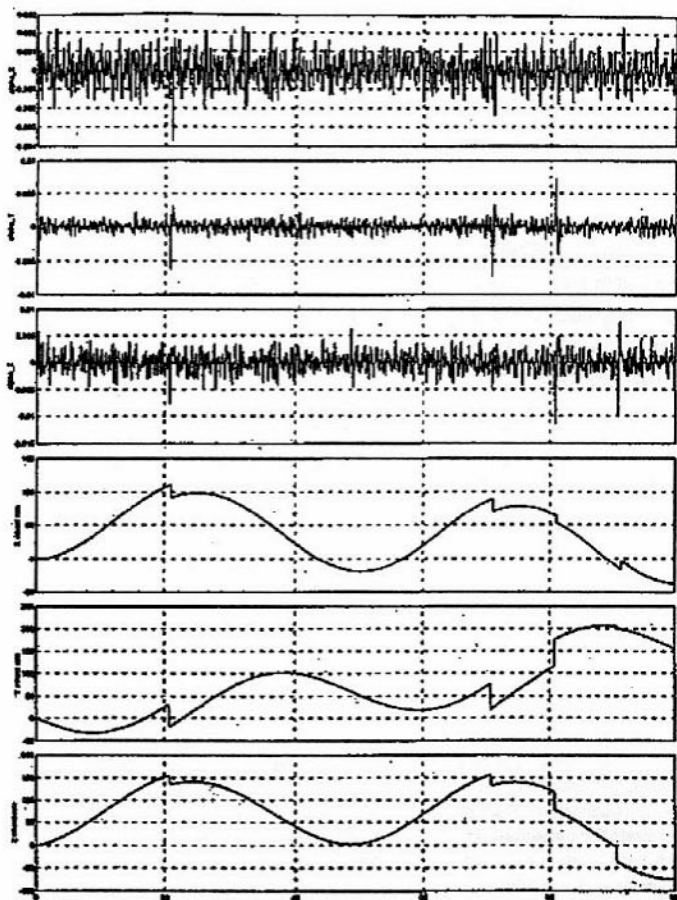
ACS Performance Issues

To meet the mission requirements, the MOST satellite needs an attitude control system designed to a performance level that few (if any) previous microsats have been able to achieve. The MOST ACS specified here is based on concepts (star sensing for attitude estimation, reaction wheels for attitude actuation) that have been used successfully in many larger satellites to achieve comparable or better performance that required for MOST; the basic approach is known to be sound. The main issue is whether a set of ACS components can be found for this three-axis ACS design that are compatible with the small mass, volume, power and cost budgets of the MOST mission.

Deriving from this main issue are the following questions:

- **Reaction Wheel Sizing:** Can reaction wheels be found that have enough torque and angular momentum capacity to achieve their requirements, and still be small enough, and low enough in mass (about 1 kg) and power consumption

Component	Mass Allocation (kg)	Average Power Allocation (W)
Rate Sensors (4)	1.0	0.3
Star Sensor (DSP)	0.5	1.0
Magnetometers (2)	1.0	0.3
Sun Sensor (1)	0.5	0.1
Reaction Wheels (4)	3.5	6.0
Magnetorquer Coils (6)	4.0	1.0
Total	10.5	8.7



Attitude Control Performance Analysis Results. This figure shows the results from a 100-minute (approximately 1-orbit) ADACS simulation of the MOST ACS, for the baseline 785 km altitude, circular, dawn/dusk, sun-synchronous orbit. The top three strips show the yaw, pitch and roll pointing errors of the satellite bus with respect to the target star direction, in units of degrees. The bottom three strips show the yaw, pitch and roll reaction wheel speeds during this period, in units of RPM. Environmental perturbation torques include gravity gradient, atmospheric drag, solar radiation pressure and residual magnetic moment. Internal perturbation effects include reaction wheel friction and damping. A 10 Hz attitude control software process is modelled that includes Kalman filtering of rate sensors and the star sensor (the latter being sampled at 1 Hz) to estimate attitude, and inner-loop feedback control of reaction wheels. The effect of the angular momentum dumping portion of the controller is evident from the reaction wheel speed plots; sinusoidal variations in speed, resulting from compensation for slowly-varying external environmental torques are combined with abrupt speed changes, due to actuation of the magnetorquers acting to reduce wheel speeds whenever the external magnetic field direction and strength is favourable. The attitude control accuracy is maintained to acceptable levels, below 0.005° , despite these disturbances.

(about 2 W), as well as in cost (below \$50K each) to be compatible with the system constraints on these resources?

- **Magnetorquer Sizing:** Can magnetorquers be specified, that are able to successfully desaturate the reaction wheels so as to prevent them from accumulating excessive angular momentum, using the power level that the satellite bus has available for this function (about 1.5W average, 15W peak)?
- **Star Sensor Accuracy, Reliability and Speed:** Can a sufficiently accurate (about 1 arc-sec) star sensor function be implemented within available computer resources on the satellite, using the image data from the telescope?

ics of the MOST satellite and its reaction wheels, and the orbital dynamics of the satellite's orbit. It includes models of several environmental torques (drag, solar radiation pressure, gravity gradient, magnetic bias). It also includes models of the attitude control system's multi-level computational processes, for each of the control modes discussed here, and of internal disturbances such as reaction wheel friction and damping.

- A reaction wheel sizing analysis was conducted. Closed-loop fine-pointing mode operations were simulated, with environmental disturbances active. Simulations of the detumbling and slew modes were also carried out; the results were

- **Attitude Estimation Accuracy:** Can a sufficiently accurate (about 10 arc-sec) estimate of satellite's attitude be maintained between star sensor measurements, to allow accurate location of target-star centroids within the science CCD field of view?
- **Attitude Control Accuracy and Stability:** Can the satellite's pointing be controlled precisely enough (to within about one arc-minute) over the duration of a 100-second photometry integration period, to keep the target star image within a small integration box area of the science-data CCD for the duration of the measurement?

These questions have been investigated by a team at Dynacon (supported by the CSA's Space Technology Branch):

- A requirements specification for a microsat-compatible High Performance Attitude Control (HPAC) subsystem was formulated, encompassing the MOST system's ACS requirements.
- A design concept for the HPAC subsystem was conceived, employing the components and concepts discussed in this paper.
- A detailed simulation of the HPAC and the MOST satellite was made. This was assembled within the Xmath SystemBuild simulation environment, based on a set of Attitude Dynamics and Control Simulation (ADACS) modules that Dynacon had available from previous projects. The ADACS MOST simulation models the attitude dynam-

combined to estimate worst-case reaction wheel angular momentum excursions (0.1 N-m-s) and torques (0.02 N-m). Suppliers for small reaction wheels were surveyed, and the angular momentum capacity, torque capacity, mass, power and price for each was compared against the MOST requirements.

- A magnetorquer sizing analysis was conducted. A magnetorquer activation control strategy was devised, using magnetometer measurements to determine when the external field strength and direction were suitable to activate each torque coil. This strategy took into account the limited power available to operate the coils. To be conservative, on/off switching logic was tested rather than the more-optimal multi-current-level approach. Operation of this strategy was tested via simulation for fine pointing, detumbling and slew control modes, and a coil size and current level found that is achievable within the available bus power and mass constraints, and is compatible with the selected reaction wheel size.

The main conclusions from these analyses were:

- There exist available magnetometers, magnetorquers and sun sensors that are compatible with the MOST ACS design.
- There are very few small reaction wheels available commercially, and the cost for these components remains rather high. Several available reaction wheels were identified which come close to meeting the MOST requirements; one reaction wheel at an advanced stage of development was found which meets all requirements, at a reasonably low anticipated price. Analysis of the star sensor software feasibility is still underway.
- ADACS predictions of the performance of the MOST ACS show the performance requirements being met with comfortable margins, for all three ACS operating modes (detumbling, fine pointing and slewing), using realistic combined models for all applicable external attitude disturbances, as well as internal disturbances including reaction wheel friction (see accompanying figure for details).

AMSAT and MOST

In August 1997, AMSAT-NA was invited by Dr. Robert E. Zee of the University of Toronto Institute for Aerospace Studies (UTIAS) to participate in the MOST mission. This invitation was followed by a presentation given by Dr. Zee at the AMSAT Space Symposium on October 17, 1997. Negotiations were then initiated to determine the precise role of AMSAT in the MOST project, and the economic and educational benefits to the amateur radio community.

Significant progress has been made in the formulation of an agreement between UTIAS and AMSAT-NA with the vision of making MOST the next amateur-class satellite after Phase 3D. In exchange for help with the design, assembly and test of MOST, AMSAT is offered the space and power to pursue advanced amateur radio interests. Moreover, AMSAT is expected to receive funding from the MOST project in return for their participation. The University of Toronto Institute for Aerospace Studies (UTIAS) has the prime responsibility of developing the various subsystems for MOST and looks forward to working side by side with AMSAT personnel in pursuit of their mutually supportive goals.

As a University of Toronto microsat project, MOST is to be built and tested at UTIAS. The member organizations and their lead responsibilities are summarized below. Any microsat team, of course, must have cross-disciplinary personnel that can provide support in every aspect of the mission. For brevity, however, only the primary duties of each organization are specified.

University of Toronto Institute for Aerospace Studies

- Bus Subsystems
- Satellite Integration
- Satellite Ground Operations

Dynacon Enterprises Limited

- Mission Design/System Design/Payload Interface
- Develop Overall Bus Design
- Attitude Control System
- Project and Engineering Management

AMSAT-NA

- Support UTIAS Subsystem Design, Build, and Test
- #### University of British Columbia

- Instrument Design, Build, Test
- Science Data Analysis

Canadian Space Agency/Spacecraft Engineering Directorate

- Qualify Bus Design
- Satellite Test
- Launch Campaign

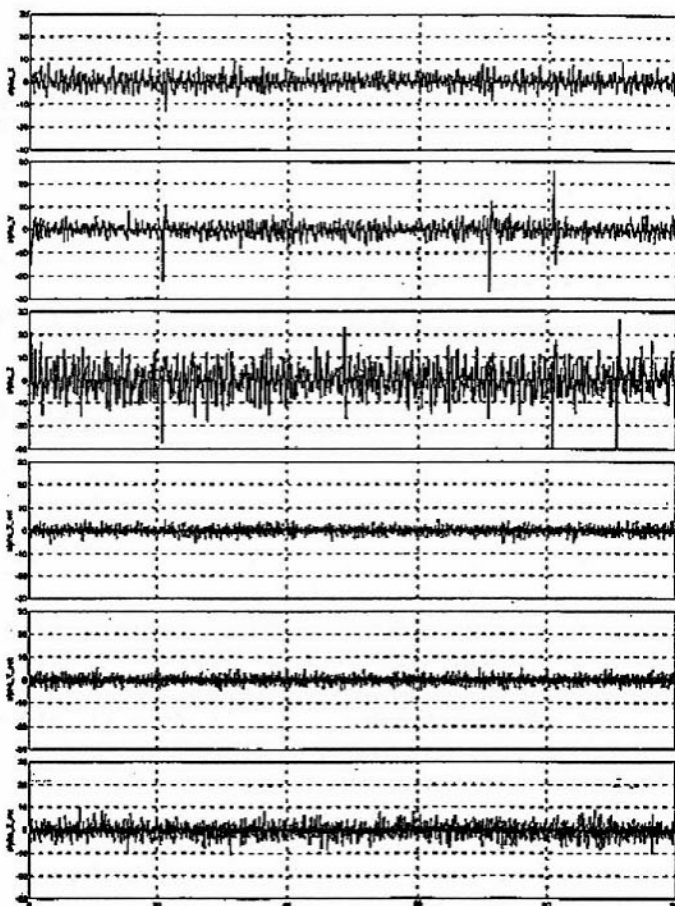
A team of AMSAT engineers, including AMSAT president Bill Tynan, W3XO, visited the University of Toronto Institute for Aerospace Studies in December 1997. The purpose was to review the conceptual design of the MOST bus as proposed by University of Toronto graduate students who have been working on the project since September 1997. As one of their final requirements for a newly established microsat design course at UTIAS, the students gave presentations to the AMSAT team and received feedback. The work done

by the students, together with the design changes proposed by the AMSAT team have been integrated into the MOST Phase A study submitted to the Canadian Space Agency at the end of 1997. AMSAT's technical review and input has proved most valuable in winning the rest of the microsat contract, bringing to bear the full weight of AMSAT's proud heritage in satellite design. Based on the merits of our team alone, it is anticipated that the Canadian Space Agency could not, in good conscience, deny us our exciting and fruitful future.

Presently, AMSAT has expressed an interest in gaining more experience with L-band and S-band communications.

Together with the high data rates required by the MOST science mission, AMSAT members are presented the challenge to develop the radios and ground station hardware required for effective digital communications at microwave frequencies. As a result of MOST, AMSAT members will gain much broader experience with S-band than previously possible. Envisioned is a redundant pair of radios with L-band uplinks and S-band downlinks. Two sets of frequencies are needed – one for ham radio communications, and the other for the telecommand and telemetry associated with the science mission. During normal satellite operations, the *Amateur Radio frequencies will be used only by the Amateur Radio community.*

It is expected that multiple ground stations will be established to permit fair satellite sharing between AMSAT and the MOST science



Altitude Estimation Performance Analysis Results. This figure shows the results from the same ADACS simulation of the MOST ACS as on the previous page. The top three strips again show the yaw, pitch and roll pointing errors of the satellite bus, this time in units of arc-seconds. The bottom three strips show the yaw, pitch and roll attitude estimation errors—the difference between the body angles estimated by the Kalman-filtered star- and rate-sensors, and the actual body angles—expressed in the same units. The attitude pointing errors are generally below 10 arc-seconds, and the attitude estimation errors are generally well below 5 arc-seconds; these levels of performance are comfortably adequate to achieve the MOST mission requirements using the planned science telescope design.

team. This is necessary since the main ground station will either be located at the University of Toronto or Canadian Space Agency headquarters (just outside Montreal). Short pass times (10 minutes maximum) and make MOST unavailable to Amateur Radio enthusiasts in the eastern United States whenever science data is downloaded. As a minimum, therefore, ground stations set up in Vancouver and Toronto are necessary to retrieve science data using each station on alternating days. Longer usage periods are possible if extra ground stations are constructed in Midwest, or if cooperative networking can be established between the University of Toronto and American universities that already have successful telemetry and telecommand centers.

Conclusions

The MOST Mission provides an exciting opportunity to carry out stellar photometric observations, free from the contaminating effects of the Earth's atmosphere, using an affordable microsat platform. The low mission cost enables the mission to be dedicated to the single task of long-duration photometric observations of a few selected target stars; larger and more expensive space (and ground-based) telescopes cannot afford to spend the time to collect the necessary long-duration observation records. Combined with the fundamental importance of the observations that will be taken, the low cost makes this a remarkably cost-effective space science mission.

Given the ability to conduct long-duration observations for each target star, a very small telescope is capable of collecting enough light to produce a sufficiently-high S/N ratio for each observation data point, which in turn will result in a sufficiently-high S/N ratio in the post-processed data to permit important stellar characteristics to be resolved. This instrument is small enough to be physically accommodated on a satellite platform that is very similar to many microsats that have been successfully flown at costs compatible with the MOST budget.

Mission analysis indicates that there exist orbits which have the characteristic necessary

to the MOST Mission—orbits having a CVZ which dwells on target stars for longer than 4 weeks. These sun-synchronous orbits are the destination of many Earth-observing satellite missions, making it likely that a low-cost secondary-payload launch opportunity will be found for MOST.

The main capability which MOST needs, which has not been demonstrated in other microsat missions, is high-accuracy and high-stability attitude control. Development effort has been focused on this satellite function, and a candidate design for a High Performance Attitude Control (HPAC) subsystem has been established using a combination of commercially-available and custom-developed hardware and software, which meets the MOST ACS requirements. This HPAC design uses approximately the same mass, and about 8W more power, when compared to a gravity-gradient-boom based microsat ACS,

Verification of this design has been carried out using Dynacon's ADACS high-fidelity attitude dynamics and control simulation package. Results indicate that the MOST ACS requirements are met by the HPAC with a comfortable margin.

The MOST mission represents an opportunity to pursue advanced Amateur Radio interest in exchange for AMSAT's invaluable technical assistance in the development of the MOST

microsatellite. AMSAT also benefits by obtaining financial support for their participation. Anticipated to be the next amateur-class satellite after Phase 3D, MOST serves to strengthen the Radio Amateur Satellite Corporation, both in the immediate and distant future. ■

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Why Not Use AO-10 When Signals are *FMing*?

The chances of damaging AO-10 by uplinking during *FMing* are probably remote. The caution mainly stems from a theoretical consideration. AO-10's latching relays are set to the omni antenna and the transponder is on in Mode-B configuration. This all turns out to be perfect since we can't control the attitude, etc. Each time there's a power spike the chance exists that the IHU could have a *seizure* and blurt out a pulse to switch the antennas to high-gain, switch the transponder off or whatever. Of course these spikes occur every time we come out of eclipse, but the idea is to do what we can to minimize the number of power spikes. Occasionally spikes have *activated* the IHU in the past and caused the beacon to send out nonsensical data rather than the current constant carrier for short periods of time. ...and it isn't clear when AO-10 switched to the omni antenna, so I guess such things may have happened in the past. I suppose there are also some considerations regarding the effects on the transponder of operating it so far off its normal voltage/current curve, but, again, this doesn't seem to have caused a problem after many years.

Antenna Configuration

AO-10 is using its omni antenna. This is fortunate, given the fact that its attitude cannot be controlled or even accurately determined. Best signals should correspond to a squint angle of 90°. Higher squints cause partial shielding of the omni by the slowly rotating spacecraft and may account for QSB. The omni should TX/RX a non-circularly polarized signal. However, multiple users have noted that during periods of QSB, switching the direction of circular polarization (R/L) on the 145 MHz downlink seems to immediately improve the signal.

AO-10's Argument of Perigee

Because of AO-10's relatively low inclination, its argument of perigee changes much more rapidly than did AO-13's. The current value is 165°, placing apogee slightly in the southern hemisphere. However, the ArgP is increasing at about

0.28 degs/day and apogee has been moving northward from its southern most point when ArgP = 90°. On approximately January 1, 1998, ArgP will be 180°, meaning apogee will cross the equator and progressively move into the northern hemisphere, peaking when ArgP = 270° on approximately December 12, 1998. So for all of 1998 and virtually all of 1999, the apogee of AO-10 will be in the northern hemisphere.

AO-10's ALON/ALAT

Because it's IHU has been dead for many years, AO-10's attitude cannot be precisely determined. However, it's orbit is well known and if we assume that at the midpoint of its *sleep* cycles, one end of the S/C is pointed directly at the Sun, we can guesstimate an ALON/ALAT. These calculations may be off by at least +/- 20°. Also, we don't know, based on illumination alone, which end is pointing at the sun, so the ALON/ALAT's given could be reversed (ALON +/-180, ALAT change sign). The last sleep cycle seemed to have it's low point on about May 25, 1997. On that date the Sun was at SAZ(ALON)=158, SEL(ALAT)=47 with respect to AO-10's orbital plane. Thus, if the satellite were pointing directly at the sun on May 25, 1997, it's ALON/ALAT would have been 158/47. Based on some subsequent signal evaluations, I believe this is the more correct orientation, rather than the reverse (338/-47). Also remember that the omni antenna is active so ALON/ALAT is not really highly important, although it does give some information. Optimal signals to/from the omni antenna occur when SQUINT = 90°.

James Miller, G3RUH has developed a suite of software programs running on the Acorn Risc Computer systems for commanding and orienting AO-13 and other Phase 3 satellites. I have modified and *ported* many of his routines to run in Windows format on PC-type machines, and to allow use with multiple satellites. The following Tables were derived from my modifications of James' software. Any errors are mine.

Figure 1 shows the effect of ALON/ALAT on solar illumination on

AO-10 was launched on June 16, 1983 on an Ariane-2 rocket from Kourou, French Guiana. Early minor problems precluded reaching a high (Molniya orbit) inclination and a resulting inclination of 26° was obtained. The orbit of AO-10 is highly stable (i.e. hundreds of years) and the satellite will not suffer the re-entry fate of AO-13. Rad-hardened RAM memory was not available for AO-10's Internal Housekeeping Unit (IHU) and it failed in December 1986 due to exposures to high levels of radiation. Since that time the spin/cycle (S/C) has been uncontrolled and its Z-axis spin rate has been slowly decreasing. AO-10 remains in Mode-B using the omni antenna. AO-10 on board batteries have failed *open* and AO-10's power is solely derived from the solar panels. When the S/C enters eclipse, the transponder fails immediately.

Why Does AO-10 Periodically Sleep?

AO-10's usually twice yearly *sleeps* are not due to solar eclipses. A solar eclipse, from the satellite's point of view, occurs when the Earth comes between the satellite and the Sun. This does indeed happen during certain seasons of the year on virtually every orbit, but for rather short periods of time. The phenomenon happening with AO-10 sleeps is related to the fact that spin-stabilized satellites always point at the same spot in space (allowing for minor perturbations). As the satellite, along with the Earth, rotates around the Sun, the Sun appears to the satellite to rotate around it. If the orientation isn't changed, and assuming ALAT is within the range of the ecliptic (solar plane) then twice a year the sun will hit either the antenna end or the motor end of AO-10. During this time, the solar panels will be in darkness, or at least at light levels insufficient for adequate power generation. However, there's sunlight on the END of the satellite, so it's not in an eclipse. The batteries on AO-10 are totally dead....when it goes into a true eclipse it instantly loses power and power/transponder instantly returns a bit later (usually minutes) when the satellite emerges from the Earth's shadow.

September 27, 1997. The center of the *hole* at the upper right is an approximation. ALON/ALAT 90/25 may be thought of as the sun's position. If the chart were more inclusive, the mirror *hole* at the lower left would be more clearly in view. The numbers listed are the sun's angle on the solar panels (0 = directly overhead, maximum illumination). Negative numbers indicate the Sun favoring the antenna end of the satellite. Positive numbers mean the Sun is towards the motor end.

A spin stabilized satellite should always point at the same place in the celestial sphere. ALON/ALAT, however, is based on orbital plane coordinates, so as the orbit changes, primarily due to precession of RAAN and ArgP, the values of ALON/ALAT change, even though the S/C is still pointing at the same celestial point.

Figure 2 shows the weekly effect of orbital precession on AO-10's ALON/ALAT, given an ALON/ALAT of 151.2/41.9 on September 27, 1997. Note that the illumination drops off rapidly over the next few weeks.

Has AO-10's Attitude Changed?

The last sleep phase for AO-10 that I'm aware of centered on February 10, 1996. At that time the solar location in the orbital plane was SAZ/SEL = 113/-40. If AO-10's ALON/ALAT = 293/40 at that time (SA = 90, Ill = 0%), then by orbital plane

precession effects alone, on May 25, 1997, ALON/ALAT should = 244/14, SA = 13°, illumination = 97 percent, which clearly can't be correct so it WOULD APPEAR that AO-10 is no longer highly attitude stable....which renders the above tables of questionable value! This is in agreement with the simple observation that the six month cycle of sleep/wake has been disrupted, as no *sleep* occurred this February. The currently slow spin rate of AO-10 is probably the best explanation for the instability, especially if it continues to show apparent heading changes. If the heading once again remains stable, other *one time* possibilities for attitude disruption may be in effect.

AO-10's Spin Rate

The spin rate of AO-10 appears to be approximately 1.5 RPM. This is based on observations that I have made on multiple occasions, based on QSB cycles of the beacon. When the attitude of AO-10 is such that the omni antenna is partially blocked by the S/C, the QSB comes in 13+ second intervals. Two of the intervals are exactly the same in duration and depth, the third is distinctly different. The repetition of this cycle is convincing that a set of three fades = 1 revolution, not 3 revolutions. Thus $1/(13 \text{ secs} * 3)/60 = 1.5 \text{ RPM}$. The three fades/revolution are due to the tri-lobed shape of AO-10. The reason for the dis-symmetry of one fade is not clear, but may be related to damage sustained when

AO-10 struck a portion of its launcher early in its life.

Why has AO-10's Spin Rate Decreased?

The best reason for this is *magnetic damping* as the conductive body of the S/C crosses the earth's magnetic field lines, especially around perigee. The phenomenon was quite pronounced with AO-13, because of its lower perigee.

AO-10 Summer Eclipse Season

AO-10 began its summer eclipse season on July 2, 1997 at 18:24 UTC, Orbit #10568, MA = 2. During this eclipse season, there are eclipses just after perigee on every orbit. These progress to a maximum eclipse length of 35 minutes each orbit (MA: 4 - 17) during the August 26 - September 5, 1997 time period. This season ended on September 30, 1997.

The next eclipse season will begin on January 23, 1998. Because of AO-10's slowly precessing orbital elements, these will occur closer to apogee and be considerably longer in duration. Maximum duration will be 95 minutes!!! in early February 1998.

Last Lunar Eclipse

AO-10 is occasionally eclipsed by the moon rather than by the Earth, the much

AO-10 ILLUMINATION TABLE / W4SM																			
1997	Sep	27 [Sat]	SEL = -23.7 SAZ = 260.6 ArgP = 155.0 RAAN = 124.7 Incl = 26.2																
ALAT	260	250	240	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90	80
70	-04	-04	-05	-06	-08	-10	-13	-16	-19	-22	-26	-29	-33	-36	-38	-41	-42	-43	-43
65	01	01	00	-02	-04	-07	-10	-14	-18	-22	-26	-30	-34	-38	-42	-42	---	---	---
60	06	06	05	03	00	-03	-07	-11	-16	-21	-26	-31	-36	-40	-40	---	---	---	---
55	11	11	09	07	04	00	-04	-09	-14	-20	-25	-31	-37	-42	---	---	---	---	---
50	16	16	14	11	08	04	-01	-07	-12	-18	-25	-31	-37	-44	---	---	---	---	---
45	21	21	19	16	12	07	02	-04	-10	-17	-24	-31	-38	-38	---	---	---	---	---
40	26	25	23	20	16	11	05	-02	-08	-15	-23	-30	-38	---	---	---	---	---	---
35	31	30	28	24	20	14	08	01	-06	-14	-22	-30	-38	---	---	---	---	---	---
30	36	35	33	29	24	18	11	04	-04	-12	-20	-29	-37	---	---	---	---	---	---
25	41	40	37	33	27	21	14	06	-02	-10	-19	-28	-36	-36	---	---	---	---	---
20	---	---	---	42	37	31	24	17	08	00	-08	-17	-26	-35	-44	---	---	---	---
15	---	---	---	41	35	27	19	11	02	-07	-16	-25	-34	-43	---	---	---	---	---
10	---	---	---	---	38	30	22	13	04	-05	-14	-23	-32	-41	---	---	---	---	---
05	---	---	---	---	---	33	24	15	06	-03	-12	-21	-30	-39	---	---	---	---	---
00	---	---	---	---	---	44	35	27	18	09	-01	-10	-19	-28	-37	-37	---	---	---
-05	---	---	---	---	---	---	38	29	20	11	01	-08	-17	-25	-34	-42	---	---	---
-10	---	---	---	---	---	---	40	31	22	12	03	-06	-14	-23	-31	-39	---	---	---
-15	---	---	---	---	---	---	42	33	23	14	05	-03	-12	-20	-28	-35	-42	---	---
-20	---	---	---	---	---	---	43	34	25	16	07	-01	-10	-18	-25	-32	-38	-42	-42
-25	---	---	---	---	---	---	44	35	26	18	09	01	-07	-15	-22	-28	-34	-38	-40
-30	---	---	---	---	---	---	---	36	28	19	11	03	-04	-12	-18	-24	-29	-33	-36
-35	---	---	---	---	---	---	---	37	29	21	13	05	-02	-09	-15	-20	-25	-28	-31
-40	---	---	---	---	---	---	---	37	29	22	15	07	01	-06	-11	-16	-21	-24	-26
-45	---	---	---	---	---	---	---	44	37	30	23	16	09	03	-08	-12	-16	-19	-21
-50	---	---	---	---	---	---	---	43	37	30	24	18	12	06	00	-04	-08	-12	-14
-55	---	---	---	---	---	---	---	42	36	30	25	19	13	08	04	-01	-04	-07	-10
-60	---	---	---	---	---	---	---	40	35	30	25	20	15	11	07	03	00	-03	-05
-65	---	---	---	---	---	---	---	38	34	30	25	21	17	13	10	06	04	02	00
-70	44	43	42	40	38	35	32	29	25	22	19	16	13	10	08	06	05	04	04

Figure 1. AO-10 Illumination Table.

more common occurrence discussed above. On September 1, 1997, beginning at 2020 UTC, AO-10 had its sunlight partially blocked by the moon when it was at MA 195-210. The maximum occlusion was almost 50 percent and the solar angle was almost 0 percent, so there was good illumination prior to the eclipse. Information that I received from several users noted marked decrease in signal strength during this time. This is a good qualitative assessment of transponder output when we have a good measurement of change in illumination. It suggests that 50 percent solar illumination results in marked decrease in performance, perhaps due in part to deterioration of the aging solar cells. Thus, we may well be seeing marked changes in transponder performance at relatively low solar angles (i.e. the currently guesstimated -30°).

Next AO-10 Lunar Eclipse

Figure 3 outlines the next lunar eclipse affecting AO-10 March 28, 1998. A maximum eclipse of only 11 percent is reached, and the entire eclipse lasts 50 minutes. Times are in UTC. A more substantial lunar eclipse occurs in August 1998 (to be shown later).

Current Status: January 22, 1998

AO-10's signals are improving again. On December 25, 1997, I noted that there were still periods of poor signal strength and deep QSB. At that time the guesstimated solar angle was -60°, giving 50 percent illumination. However signal strength and QSB did not correlate well with squint angle, based on my guesstimated ALON/ALAT of 144/38. As we never experienced complete loss of signal/beacon during the last phase, it is difficult to refine the ALON/ALAT based on solar angle. There are two other considerations.

Observations in late December and early January by me and others including Dick Jansson, WB4FAB suggested that AO-10 may be wobbling. When listening to AO-10 out about 27,000 km or so, two distinct types of QSB were heard. One was a deep fade without FM'ing. This strongly suggests an antenna orientation-related fade, perhaps due to non-Z-axis motion (*wobble*). The second fade was also very deep and had a distinct FM'ing component like the onset of an eclipse. This suggests a fade due to increasing solar angle, again

AO-10 ATTITUDE - PRECESSION BEHAVIOR / WASH									
DATE			ALON	ALAT	SA	ILL	SEL	SAZ	ArgP RAAN
1997 Sep 27 [Sat]			151.2	41.9	-29.7	007	-23.7	268.6	155.0 124.7
1997 Oct 04 [Sat]			150.7	41.6	-36.6	000	-28.1	266.1	156.9 123.6
1997 Oct 11 [Sat]			150.1	41.3	-43.5	073	-32.0	272.2	158.7 122.5
1997 Oct 18 [Sat]			149.6	41.0	-50.4	064	-35.4	279.0	160.6 121.4
1997 Oct 25 [Sat]			149.0	40.7	-57.4	054	-38.3	286.5	162.5 120.3
1997 Nov 01 [Sat]			148.5	40.3	-64.4	043	-40.3	294.6	164.4 119.1
1997 Nov 08 [Sat]			147.9	40.0	-71.4	032	-41.6	303.3	166.3 118.0
1997 Nov 15 [Sat]			147.3	39.6	-78.4	020	-42.0	312.2	168.2 116.9
1997 Nov 22 [Sat]			146.7	39.3	-85.3	008	-41.4	321.1	170.1 115.8
1997 Nov 29 [Sat]			146.1	38.9	-92.0	005	-39.9	329.7	172.0 114.7
1997 Dec 06 [Sat]			145.4	38.5	-98.2	017	-37.6	337.9	173.8 113.5
1997 Dec 13 [Sat]			144.8	38.2	-103.1	029	-34.7	345.4	175.7 112.4
1997 Dec 20 [Sat]			144.2	37.8	-106.0	041	-31.1	352.3	177.6 111.3
1997 Dec 27 [Sat]			143.5	37.4	-108.9	052	-27.2	358.5	179.5 110.2
1998 Jan 03 [Sat]			142.9	37.0	-111.8	062	-22.8	364.3	181.4 109.1
1998 Jan 10 [Sat]			142.2	36.6	-114.7	071	-18.3	369.6	183.3 107.9
1998 Jan 17 [Sat]			141.5	36.2	-117.5	079	-13.5	374.6	185.2 106.8
1998 Jan 24 [Sat]			140.8	35.8	-120.4	086	-8.7	379.4	187.1 105.7
1998 Jan 31 [Sat]			140.1	35.3	-123.3	092	-3.8	384.1	189.0 104.6
1998 Feb 07 [Sat]			139.4	34.9	-126.2	096	0.0	388.8	190.8 103.5
1998 Feb 14 [Sat]			138.7	34.5	-129.1	099	05.7	393.5	192.7 102.3
1998 Feb 21 [Sat]			138.0	34.0	-132.0	100	10.3	398.4	194.6 101.2
1998 Feb 28 [Sat]			137.2	33.6	-134.9	100	14.8	403.4	196.5 100.1
1998 Mar 07 [Sat]			136.5	33.2	-137.8	098	18.9	408.7	198.4 99.0
1998 Mar 14 [Sat]			135.8	32.7	-140.7	095	22.7	414.4	200.3 97.9
1998 Mar 21 [Sat]			135.0	32.2	-143.6	090	26.1	420.5	202.2 96.7
1998 Mar 28 [Sat]			134.2	31.8	-146.5	084	29.0	427.0	204.1 95.6
1998 Apr 04 [Sat]			133.5	31.3	-149.4	077	31.4	433.9	205.9 94.5
1998 Apr 11 [Sat]			132.7	30.9	-152.3	069	33.2	441.1	207.8 93.4
1998 Apr 18 [Sat]			131.9	30.4	-155.2	059	34.4	448.6	209.7 92.3
1998 Apr 25 [Sat]			131.1	29.9	-158.1	049	34.8	456.3	211.6 91.1
1998 May 02 [Sat]			130.3	29.4	-161.0	039	34.6	464.9	213.5 89.0
1998 May 09 [Sat]			129.5	29.0	-163.9	028	33.7	473.4	215.4 88.9
1998 May 16 [Sat]			128.7	28.5	-166.8	016	32.2	482.7	217.3 87.8
1998 May 23 [Sat]			127.9	28.0	-169.7	005	30.2	492.6	219.2 86.7
1998 May 30 [Sat]			127.0	27.5	-172.6	000	27.7	502.1	221.0 85.5

Figure 2. AO-10's Altitude Precession Behavior

requiring non-Z-axis motion, or perhaps less likely, one or more bad solar panels.

Currently, these fades have become less pronounced out near apogee. In fact, signals strengths are now amazingly strong near apogee. So strong that it seems clear that the hi-gain antennas have once again toggled on. A *glitch switch* to the hi-gains, in combination with a bit of *wobble* would also explain the observed cyclic changes in circular polarity of the antennas. Much of the QSB can clearly be negated by changing uplink and/or downlink antenna polarity. The signal strengths vs MA also agree better with the roughly calculated squint angle for the hi-gains vs. omni antenna. It

is unclear when the hi-gains switched on, but if one listens to the beacon, short bursts of nonsensical PSK can occasionally be heard....at some point, a sporadic IHU bit may have toggled the antenna relay.

Regardless of how it happened, AO-10 is now functioning rather well, particularly out near apogee, and apogee will be moving progressively higher into the northern hemisphere during this year. If you have polarity switching capability, you can negate much of the QSB. Most users seem unaware of these improved conditions near apogee as the satellite is currently under utilized. Enjoy AO-10 while you still can. ■

AO-10 Solar Eclipses by the Moon / WASH									
DATE			UTC HH:MM	DNO	NA /256	Dist deg	Rsun deg	Rmoon deg	Obsc % Type
1998 Mar 28 [Sat]			11:33	11121	060	0.545	0.267	0.205	009% PAR
1998 Mar 28 [Sat]			11:38	11121	062	0.504	0.267	0.204	003% PAR
1998 Mar 28 [Sat]			11:43	11121	064	0.475	0.267	0.204	003% PAR
1998 Mar 28 [Sat]			11:48	11121	066	0.456	0.267	0.204	002% PAR
1998 Mar 28 [Sat]			11:53	11121	067	0.448	0.267	0.203	011% PAR
1998 Mar 28 [Sat]			11:58	11121	069	0.448	0.267	0.203	010% PAR
1998 Mar 28 [Sat]			12:03	11121	071	0.456	0.267	0.202	002% PAR
1998 Mar 28 [Sat]			12:08	11121	073	0.472	0.267	0.202	002% PAR
1998 Mar 28 [Sat]			12:13	11121	075	0.493	0.267	0.201	004% PAR
1998 Mar 28 [Sat]			12:18	11121	077	0.518	0.267	0.201	002% PAR
1998 Mar 28 [Sat]			12:23	11121	078	0.546	0.267	0.201	000% PAR

Figure 3. AO-10 Solar Eclipses by the Moon.

Observed Radiation Effects on KitSAT-1

Chris Jackson G7UPN / ZL2TPO

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KitSAT-1 (also known as KO-23 to most amateur satellite enthusiasts) was built as a collaboration between Surrey Satellite Technology Limited (SSTL) in England, and the Korean Advanced Institute of Science and Technology (KAIST) in Korea. It is built around a typical UoSAT microsat bus and contains an Amateur Radio store and forward system, Earth imaging system and radiation measuring payload.

KitSAT-1 was launched in August 1992 on board an Ariane launcher into a 66°, 1350 kilometer orbit. The radiation in this orbit is approximately six times worse than that in a typical low Earth orbit of around 600 to 800 kilometers altitude.

To reduce the costs of producing small spacecraft, SSTL uses commercial components where appropriate. In the lower 700 kilometer orbit, these components will typically outlast the useful life of the spacecraft, however, in the higher radiation environment of 1350 kilometers this is not the case. Two effects of this radiation can be observed on the spacecraft. These are Single Event Upsets (SEUs) and Total Dose Effects.

Single event upsets are bit flips in the spacecraft's memory caused by high energy particles hitting the spacecraft semiconductor memory and flipping single

bits. The on-board computers (OBC's) contain hardware and software (called EDAC - Error Detection And Correction) to automatically correct against these effects by using special error correction codes. The program memory is protected using hardware EDAC and the RAM disk is protected using software codes.

Total dose effects are caused by the continued bombardment of high energy particles and affects semiconductor components over a period of time. As the total dose effects build up, semiconductor junctions start to consume more current to switch state. As these effects continue to build up, the current consumed will increase and this can now be observed in the KitSAT-1 telemetry. The current increase from total dose effects is logarithmic and is non-reversible.

Commercial semiconductors will generally survive dose levels up to around 10k rad. In the KitSAT-1 orbit the spacecraft experiences approximately 7 rad per day, and so the 10k rad level will be reached after five years in orbit.

Looking at long term telemetry received at the UoSAT groundstation over the past few years, these effects can be seen in the 5V current monitor and the CPU current monitor. Figure 1 is a plot of the maximum CPU current. The maximum (or minimum)

current must be used as the CPU current varies depending on spacecraft activity. The cyclic variations in the current are due to the average spacecraft temperature. In the 66° inclination orbit, the spacecraft will experience eclipse periods from 0 to 40 minutes which changes the average spacecraft temperature from just above 0° Celsius to over 40° Celsius, and this varies the current consumption accordingly.

Possible failure modes

There are a number of possible failure modes that may occur. The OBC is protected with a power switch that will remove power from the module if the current exceeds a pre-set level. This is done to protect the power system in the same way that a fuse would normally be used on terrestrial based systems. This trip current is set at approximately 500mA although it too may have changed its value due to the effects of radiation. It is however probable that as the current increases a particular junction may fail which will render the computer inoperable. As the current drawn by individual junctions increases, so does the heat in that junction and this may burn the junction out.

Conclusions

While the higher orbit and lower inclination provides a great orbit for communications, both these factors increase the radiation effects on the spacecraft's electronic subsystems and thus reduce the lifetime of the mission. The KitSAT-1 spacecraft has received high levels of radiation and is starting to suffer the effects of total dose radiation. The OBC current is presently reading approximately 300mA and as such the OBC is now living on borrowed time since it is consuming over twice it's nominal current following launch. It is however difficult to predict how long it will be before the OBC fails.

The intention of this article is not to present an in depth paper on effects of space radiation, but to show amateur satellite enthusiasts that there is interesting information to be gained by collecting and analyzing spacecraft telemetry and housekeeping log files. ■

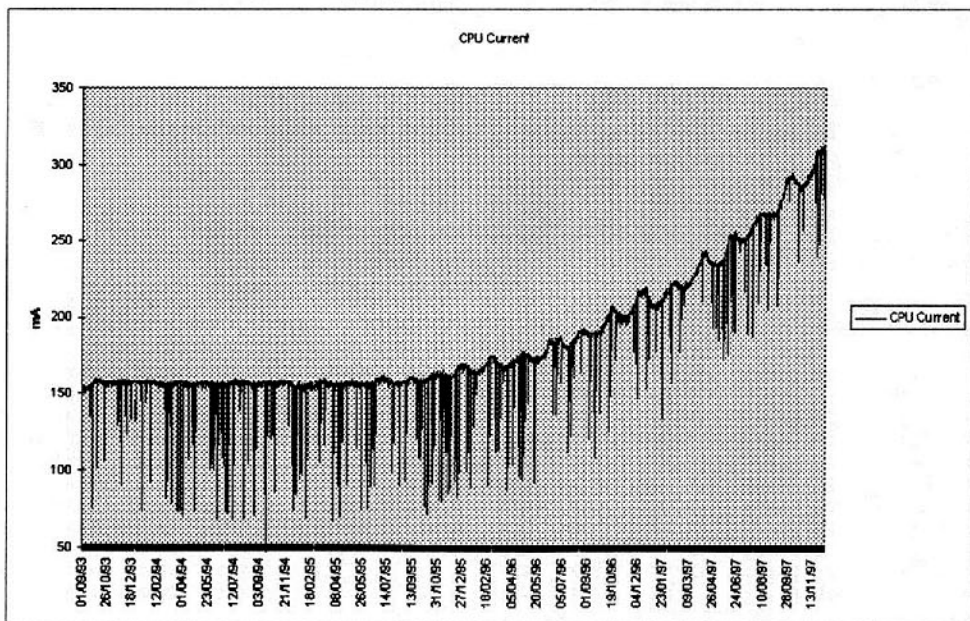


Figure 1. KO-23's Maximum CPU Current - 01SEP93 to 13NOV97

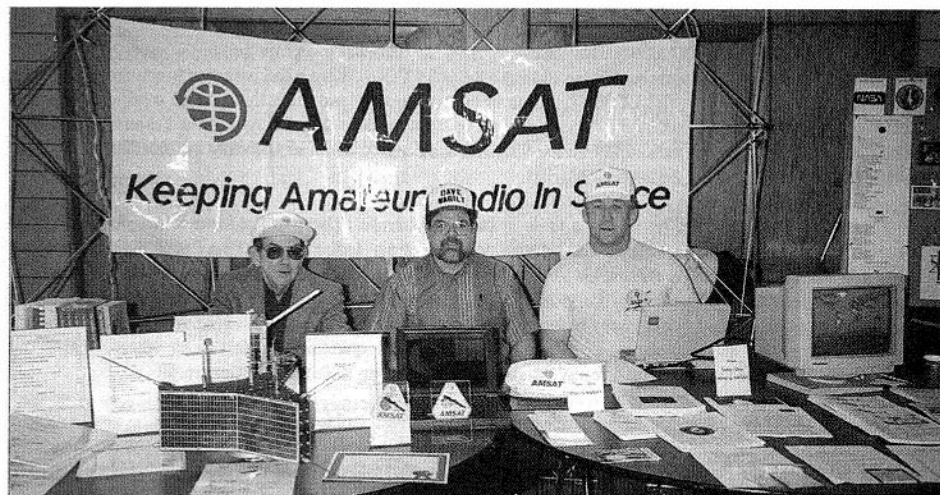
Field Ops Update: Lessons Learned from the Fleamarket Front

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Many of our members have helped in the past with representing AMSAT at major hamfests around the country. With the help of dedicated volunteers, AMSAT has a major presence at places like the Dayton Hamvention, Miami Hamboree, Orlando Hamcation, Sea-Pac in Oregon, ARRL New England in Boxboro, etc. These relatively large gatherings (up to 28,000 people in the case of Dayton) provide an opportunity for us to demonstrate our software, make available our latest books, do forums (and sometimes a Satellite Workshop), and encourage memberships.

Needless-to-say, these major hamfests can also have major costs. The cost of the booth itself (not all hamfests provide free space to non-profits) and the freight charges to ship heavy printed material to and from the team leader are the two major cost components. Martha does a great job of sizing the shipments, providing enough material to cover requirements based upon the expected attendance at the hamfest, past history, and whether there are new materials that will be in higher demand than our existing stock. In reality, many of our capable volunteers provide a presence at relatively small hamfests (1,000-3,000 attendance), such as Jacksonville and Tampa. The expectation is that the revenue generated will more than offset the cash outlay that is required. However, this doesn't always happen. In fact, you may have noticed the reduction in hamfest attendance, the relative drop in AMSAT revenues, and dropping memberships that all reflect a nationwide decline in hamfest activities. In some cases, the revenues generated have just barely exceeded the shipping and associated costs of AMSAT's attendance.

While we have a tendency to think of amateur radio gatherings as hamfests, there are a great number of small amateur radio functions that can be categorized as flea markets, swap meets, and the like that only attract several hundred attendees. While small, such occasions provide a great opportunity for our volunteers to work one-on-one with potential members and to provide a personal perspective on amateur satellites that isn't always possible at larger hamfests when there are many people stopping by the AMSAT booth. However, when our expected revenue inflow is not



Framingham Flea Market: (L to R) Arthur Rowe, N1ORC, David Reinhart, WA6ILT, and Ernie MacLaughlin, N1OHJ man the AMSAT table. Note the variety of handouts (with *Take One* signs) on the table in front of N1OHJ plus the computer monitors demonstrating satellite software.

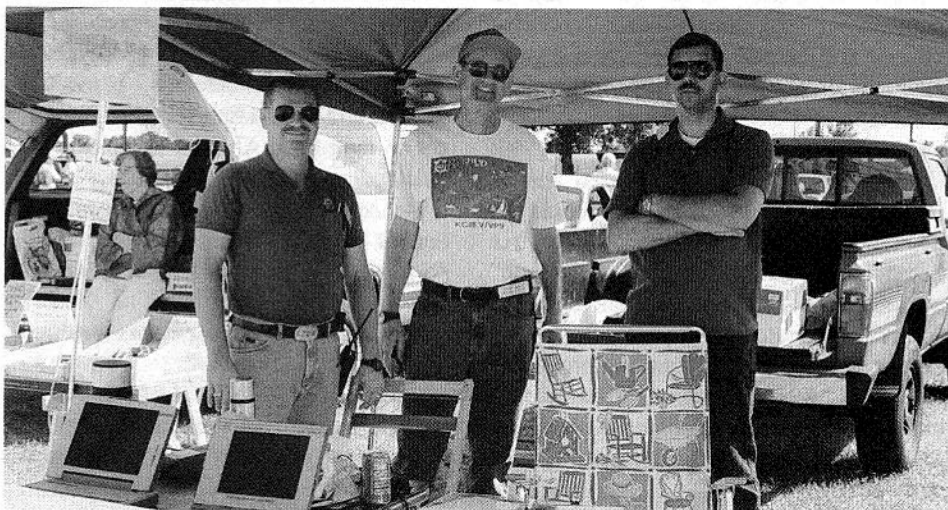
much more than the cost of providing an AMSAT presence, one has to rethink our strategy. It makes sense for local volunteers to show the flag but we don't want to spend much money on the costs of providing that presence. So, what do we do?

Two illustrations of local volunteer initiative by Area Coordinators provide some ideas on how to effectively answer this question.

Framingham Flea Market

Earlier this year, Area Coordinator Ernie MacLaughlin, N1OHJ of South Weymouth, MA, assisted by Arthur Rowe, N1ORC, and David Reinhart, WA6ILT, set up an AMSAT table at the indoor Framingham, MA flea market. Their

approach was to generate a presence with minimal support from AMSAT itself by creating their own handouts of available satellites and frequencies, utilizing the "What's AMSAT?" brochure (available from Martha), and promote new memberships. Like many AMSAT displays, they had satellite tracking software on display to help draw a crowd. More importantly, they had material available on LOCAL AMSAT activities, particularly the weekly nets that are scheduled on local two meter repeaters. For example, the weekly net run by N1OHJ every Thursday night at 2030 on the Waltham, MA repeater (146.64 MHz) was highlighted. That net has generated more than 1,000 check-ins since its inception and a certificate is issued to anyone who has checked into the net 10 times. In addition,



Sussex New Jersey Hamfest: (L to R) Mike Surmich, K2QW, John Tworsky, KC2EV, and Mario Karcich, K2ZD help out at the AMSAT booth. Power for the laptops was supplied by an inverter that was fed from the battery system of NB2F's truck parked behind the tent.

GRASS ROOTS on the GRASS

Dee Interdonato, NB2F

NJ AMSAT Area Coordinator

With all the advertisements and flyers put out by AMSAT-NA, there is the *personal* touch that goes along with selling the ideas of "SATELLITES." Some of us give money and think that it'll all work out. "Let the other guy (or gal) do it." Sometimes it takes a few more steps to assist in passing the word around and letting the rest of the amateur radio community know what AMSAT has on its mind and what the satellite community has to offer.

I started a few years ago by taking a table at our local hamfest (Bergen Amateur Radio Association in Teaneck, NJ) to see whether revenues and interest could be generated to help AMSAT with their big project, Phase 3D. While the revenues were a bit skimpy at first, I generated questions and answered many more to show what is necessary to operate on the "birds." The ideas of what it takes to do so are so varied that it could take a 20-minute discussion to help out a newer satellite enthusiast compared to a simple one sentence response to more experienced satellite users. If I couldn't answer their question, I'd tell them where to find the information. You'll be surprised how many ears are listening along with the questioners!?

The AMSAT books that are being produced lately are wonderful help guides to those that need to know more about a particular subject. I display them under a Plexiglas sheet so as to distinguish between the FREE items on top (AMSAT Flyers and Membership applications etc.) and the items that are available for a donation to AMSAT (books, patches etc.) underneath. Demonstrating tracking programs (whenever possible) helps to give prospective satellite users an understanding of what is needed to get the correct time and position of the satellite they wish to listen to or operate through. This is the biggest problem for satellite novices to comprehend. Keplerian data is a simple mystery to unravel for them, but it may take more than a few minutes to get them oriented.

Demos of actual operation through a satellite is a great attraction but I like to do that at an operational event such as Field Day or at a Special Event station. At a hamfest, there are usually so many HT's in operation that you may never be able to have a successful contact. I show a QSL I received from a station in NY that was using his mobile rig with a whip antenna to talk with me via AO-27 in FM mode. It includes a picture of his car outside his work QTH because I was his first satellite contact!

At smaller functions, such as the Sussex, NJ which was held outdoors, I bring an inverter to power the laptops for demos and bring my Pop-up tent to provide shelter for the table of goodies. An AMSAT banner obtained from Martha strung across the front does a great job of identifying the booth. The photo at Sussex shows (L to R) Mike Surmic, K2QW who owns one of the laptops, John Tworsky, KC2EV who helps me by fabricating my satellite mounts, and Mario Karcich, K2ZD who is a new AMSAT member. It helps to have a few others helping so you can take the time to look around while they're manning the booth. I can set up this type of operation almost anywhere.

After hearing about a few adventurous souls wondering what it is like to subject yourself to an onslaught of questions about the *birds*, this should give you a better understanding of what to expect. Remember, we were all new to satellites at one time. If we want the satellite programs to continue to grow, some people have to become the Grass Roots (see the grass in the picture) of the satellite community and actually become the person that is called upon locally for information, both operational and technical, that can be timely to individuals and groups. Try it! Give a call to your local coordinator and ask to assist the next time he (or she) will be *sitting on the grass!*

a display of SAREX QSL cards was set up since N1OHJ had worked the shuttle. In both cases, the local touch increased interest and helped attendees gain a good appreciation of what was happening in their local area.

A second approach they used was to take advantage of video materials to demonstrate satellite communications. As noted in an earlier "Field Ops Update" column, Martha has copies available of the Inside Space feature on AMSAT that we've been given permission from the producers to show at AMSAT functions. This material explains Phase 3D, includes a demo of AO-27, and provides background on the story of AMSAT.

So, for the cost of sending some AMSAT flyers, a video tape, and a banner

from Martha and greatly supplemented by a local flavor of information and display, AMSAT had a strong presence at Framingham which created great interest, several new memberships, some cash (\$200), and motivation for new people to get on their local AMSAT nets. This is an outstanding example of creating a local presence that provided significant local benefit without incurring much cost to AMSAT or to the volunteers themselves.

Sussex, NJ: "Grass Roots on the Grass"

The second illustration is from Dee Interdonato, NB2F, of Lodi, NJ who was recognized at Toronto for his outstanding contributions to AMSAT as an area coordinator. His observations can be summarized "Grass Roots on the Grass"

because he literally represented AMSAT at an outdoor hamfest in Sussex, NJ. (See sidebar.) Dee makes two excellent points: 1) the need for volunteers to step forward and make AMSAT visible on the local level, and 2) the benefit of having time to answer questions and generate interest from people not currently on the satellites.

As Dee note in his article, "If we want the satellite programs to continue to grow, some people have to become the Grass Roots (see the grass in the picture) of the satellite community and actually become the person that is called upon locally for information, both operational and technical, that can be timely to individuals and groups. Try it! Give a call to your local coordinator and ask to assist the next time he (or she) will be *sitting on the grass!*"

Summary

Please take the time to determine how YOU can help generate local interest in AMSAT. While large hamfests are fun and can provide revenue and new memberships for our organization, I suspect that there are many more small functions such as swapmeets than large hamfests in many parts of the country. Our ability to maintain our levels of membership is dependent in part upon keeping interest in AMSAT high. We can be very successful without the need to have a wide variety of AMSAT materials to be shipped to these smaller functions. The key to success at smaller functions is to create an interesting display, spend time working one-on-one with those interested in learning more about satellites, and highlight a local perspective of working the satellites.

The AMSAT WWW page is a great place to get materials for distribution at hamfests. The *What is AMSAT* page can be selected from the WWW site's main page and printed as a handout. There are also materials on Phase 3D (such as *What is Phase 3D?*) which can be found clicking the *AMSAT-NA Press Releases* section on the main menu of the WWW page.

I am very interested in learning about your success stories in representing AMSAT at smaller functions. If you have ideas that you would like to share, examples of showing the flag at relatively small gatherings, or perhaps provided a unique perspective on local AMSAT activities, please send me an e-mail or letter. ■

Remote Sensing of the Ionosphere Using Satellite Radio Beacon Observations

Frank Bauregger, KV3H/6 and Christine Law, Stanford University

Anyone who has used the Radio Sputnik (RS) series satellites in Mode A is familiar with the periodic fading which occurs on the 10-meter downlink. This fading is characterized by deep nulls in received signal strength, which may occur every 2 to 20 seconds. The period of the fading varies as the satellite passes overhead. Between the nulls, the signal strength is relatively strong. This fading is called Faraday fading, and is the result of a phenomenon called Faraday rotation. Although Faraday fading is merely a nuisance to an operator copying CW or SSB signals, information obtained from the rate of Faraday fading may be used to make useful measurements of the electron content within the ionosphere. In this article I will discuss the theory of Faraday rotation and describe how one can compute the electron concentration in the ionosphere by measuring the rate of Faraday rotation fading from satellites RS-10/11, RS-12/13, RS-15 or RS-16.

Background and Motivation

The ionosphere is a very complex and dynamic medium, and its behavior is not completely understood even today. Solar radiation ionizes the upper atmosphere to produce free electrons and positive ions. Once formed, the ions are transported by processes such as diffusion, neutral winds, gravity, and electromagnetic drift. Complex chemical reactions are responsible for recombination of the electrons and ions. The net result of these processes is the ionosphere as we know it. The magnitude and shape of the electron density profiles within the ionosphere vary diurnally with solar radiation intensity, and are affected by seasonal changes and by solar disturbances as well.

Researchers have developed models of the ionosphere which attempt to represent all these processes mathematically. In order to validate the accuracy of these models, it is desirable to have efficient methods of determining the actual electron content within the ionosphere on a small time scale and spatial scale. Naturally, real-time profiles of electron density as a function of altitude above Earth's surface would be ideal. However, a more realistic and convenient approach is to compute the total electron content (TEC) of the ionosphere at many discrete locations.

Total electron content is the number of free electrons in a column of 1 meter squared cross section which extends from the observer to an arbitrary altitude, typically chosen to be well above the ionosphere. TEC is given by the expression below (1):

$$TEC = \int_{R_e}^{R_e+h} N(z) dz$$

$N(z)$ is the concentration of electrons per m^3 . R_e is the radius of Earth, and h is the upper bound on the altitude. One of the most important ways to compute TEC is by observing Faraday fading of radio signals which pass through the ionosphere. Although Faraday fading of satellite radio beacon signals may be used to characterize other features of the ionosphere, this article only deals with computing TEC.

The earliest measurements of TEC were obtained by observing Faraday fading of VHF echoes from the moon. However, the launch of Sputnik I in 1957 provided a new means of computing TEC. The 20 MHz radio beacon aboard Sputnik I was acquired by Earth based receivers, and the Faraday fading of the beacon signal led to estimates of TEC. Sputnik I also allowed researchers to characterize horizontal gradients and small-scale irregularities in the ionosphere. Since then, measurements of radio signals from many other low orbit and geostationary satellites have been used to study the ionosphere. Most notably, the ATS-6 satellite was launched into a geostationary orbit in 1974 specifically for the purpose of ionospheric study. The high altitude of ATS-6 provided electron density measurements well above the ionosphere in a region called the plasmasphere (2).

Theory

Faraday rotation gets its name as a result of experiments performed by Michael Faraday. Faraday sent light through a crystal which had an externally applied magnetic field. He observed that the polarization plane of the light rotated after passing through the crystal (3). It is interesting that the ionosphere, in the presence of Earth's magnetic field, behaves exactly like the crystal. When a linearly polarized satellite radio beacon signal passes through the ionosphere, its

plane of polarization rotates. Consider a satellite passing overhead which is transmitting with a linearly polarized antenna. As the geometry between the observer and the satellite changes, the radio wave will travel through a varying thickness of the ionosphere, thus causing the polarization to rotate. Fading of the satellite signal will occur when the polarization of the received radio signal is orthogonal to the receiving antenna. There will be two fades per 360° rotation of the polarization plane. Since the rate of Faraday rotation is a function of the electron density along the path of the radio signal, we can easily calculate the electron density along the signal path based on the number of polarization rotations which occur for a given change in path length.

In order to derive a useful expression relating TEC to Faraday rotation, it is necessary to understand how radio waves propagate in a plasma. At high frequencies, the ionosphere may be considered a neutral, lossless plasma comprising equal numbers of positive ions and electrons. Since the electrons are 2,000 to 6,000 times lighter than the ions, we need only consider interactions between the radio wave and the electrons. The electrons are in constant motion, colliding with one another at very high rates. However, in a *lossless* plasma, we assume that the plasma is tenuous, and the frequency of the collisions is much less than the frequency of the propagating wave (4). This assumption is reasonable at 10-meters, and allows us to model the ionosphere as a lossless dielectric. The relative dielectric constant of such a medium is given by the Appleton-Hartree equation (5):

$$\epsilon_r = n^2 = 1 - \frac{X}{1 - \frac{Y_T^2}{2(1-X)} \pm \sqrt{\frac{Y_T^4}{4(1-X)^2} + Y_L^2}}$$

where:

$$X = \frac{f_n^2}{f^2}$$

$$f_n = \frac{1}{2\pi} \sqrt{\frac{Ne^2}{\epsilon_0 m}}$$

$$Y_T = \frac{eB_0}{m\omega} \sin \theta$$

$$Y_L = \frac{eB_0}{m\omega} \cos\theta$$

N is the electron density (electrons per m^3), e is the electronic charge (1.602×10^{-19} Coulombs), m is the electron mass (9.1×10^{-31} kg), B_0 is Earth's magnetic field strength, and θ is the angle between the direction of propagation and B_0 . The plasma frequency, f_N , is a critical frequency at which the permittivity and the index of refraction of the ionosphere become zero. This interesting situation may be thought of as a resonance condition, whereby the ionosphere behaves like an open-circuited transmission line, and all radio waves are completely reflected. For radio frequencies above the plasma frequency, the plasma behaves as a dielectric and the radio waves pass through; however, ϵ_r and n will be less than 1.0. This is not typical of most materials we encounter in nature which have dielectric constants greater than 1.0. For radio frequencies less than the plasma frequency, the index of refraction will be imaginary. This condition results in complete reflection of the radio waves.

The Appleton-Hartree equation provides two solutions for ϵ_r . This means that for a *single* linearly polarized incident wave, there will be *two* waves propagating in the ionosphere, each with a different polarization, and each experiencing a different index of refraction. The polarizations and indices of refraction of the characteristic waves depend on the direction of propagation since Y_T and Y_L are functions of θ . A medium whose electrical properties depend on direction of propagation is called *anisotropic*. Some ferrite materials also behave in this manner, and are useful for microwave devices such as circulators. The two characteristic waves are called the *ordinary* and *extraordinary* waves. It can be

shown that the ordinary wave is a left-hand circularly polarized (LHCP) wave, and the extraordinary wave is a right-hand circularly polarized (RHCP) wave, for propagation in the direction of B_0 (downward propagation in the northern hemisphere) (6). Thus, when a linearly polarized wave enters the ionosphere, it splits into LHCP and RHCP ordinary and extraordinary waves, each carrying equal power. The waves propagate with different phase velocities because the indices of refraction are different for the ordinary and extraordinary waves. For downward propagation in the northern hemisphere, the velocity of the extraordinary wave is greater than the velocity of the ordinary wave. When the waves exit the ionosphere, they recombine to form a linearly polarized wave, but the resultant E-field vector no longer points in the same direction as the incident wave E-field vector. Because the extraordinary wave travels faster than the ordinary wave, the resultant E-field vector will have rotated counter-clockwise by an angle Ω , as seen by an observer looking upward. Angle Ω is called the Faraday rotation angle. This situation is shown graphically in Figure 1.

The equation for the Faraday rotation angle Ω is (7):

$$\Omega = \frac{e^3 \lambda^2 B_0 \cos\theta \sec\chi}{8\pi^2 c^3 \epsilon_0 m^2} \int_{R_e}^{R_e+h} N(z) dz$$

radians

Angle χ is the angle between the zenith and the direction of propagation. The satellite is assumed to be in a circular orbit at altitude h . See Figure 2.

Note that the integral in the above expression is the equation for TEC. This suggests that the expression may be inverted to solve for TEC:

$$TEC = \int_{R_e}^{R_e+h} N(z) dz = \frac{8\pi^2 c^3 \epsilon_0 m^2 \Omega}{e^3 \lambda^2 B_0 \cos\theta \sec\chi}$$

It seems that if we were able to measure Ω , and could somehow calculate θ and χ , we would have TEC. However, it is not possible to determine the *absolute* value of Ω for a low orbit satellite such as RS-12. This is because of the ambiguity regarding the number of 360° rotations which have occurred as the wave passed through the ionosphere. However, we can easily measure relative changes in Ω . Consider a 10-meter receiver connected to a simple dipole antenna. The nulls of the radio beacon signal correspond to those times when the polarization of the E-field is orthogonal to the axis of the dipole. This occurs for each 180° rotation of the E-field vector. Thus, $\Delta\Omega = 180^\circ$ (π radians) between each null. Given this information and the position of the satellite at each consecutive signal null, we may arrive at an expression for TEC as follows:

$$TEC = \int_{R_e}^{R_e+h} N(z) dz = \frac{8\pi^2 c^3 \epsilon_0 m^2 \pi}{e^3 \lambda^2 B_0 [\cos\theta_2 \sec\chi_2 - \cos\theta_1 \sec\chi_1]}$$

At this point, it should be mentioned that Faraday rotation techniques do not actually measure the total electron content of the ionosphere up to any arbitrary height. Since Earth's magnetic field intensity falls as the inverse cube of the height above Earth, Faraday rotation will be minimal at very high altitudes. Therefore, Faraday rotation methods only measure the electron content up to an altitude of about 2,000 km (8). Strictly speaking, the measure of electron density

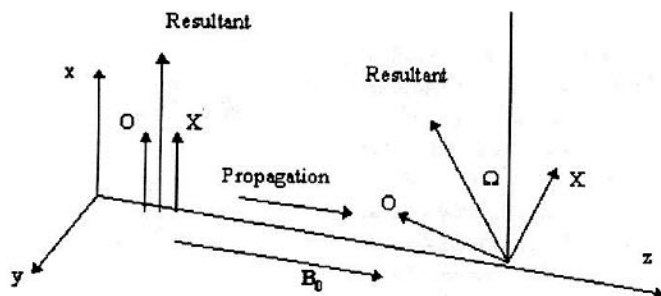


Figure 1.

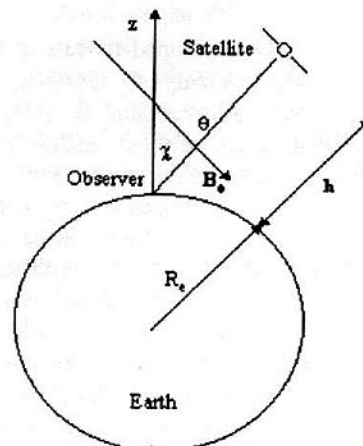


Figure 2.

obtained from Faraday rotation experiments is called the *Faraday content*, not TEC (9). However, for the purposes of the experiment described in this article, we will refer to the measured electron content as TEC.

Measuring TEC

This section describes the procedure for measuring TEC in detail. Any moderately well equipped amateur radio station can measure TEC from one of several satellites. The satellites listed in Table 1 have linearly polarized transmit antennas and are thus suitable for Faraday rotation experiments.

Table 1 - Selected Satellites for Faraday Rotation Experiment

Satellite	Altitude	Frequency
RS-10	1,000 km	29.357 MHz
RS-12	1,000 km	29.408 MHz
RS-15	2,000 km	29.3525 or 29.3987 MHz
RS-16	470 km	29.408 or 29.451 MHz

We have made TEC measurements with RS-12 and RS-15. At the time of this writing, RS-10 is not operational, and we have not heard the RS-16 10-meter beacon. Only the 10-meter beacons should be used since they provide the most sensitivity to Faraday rotation.

First, choose a satellite to observe and determine when it will be overhead. Set up your receiver to copy the CW beacon and connect it to an outside dipole antenna. The nulls will be deeper and easier to record if the dipole is at least a quarter wavelength high and is free of nearby interfering objects. As the satellite passes overhead, use a digital watch to record the exact times of the beacon nulls. You may want to record the beacon signal using the sound card on your computer so you can actually visualize the sound waveform and verify your measurements later. Next, using your satellite tracking software, note the positions of the satellite (azimuth and elevation angles only) at the times of two consecutive beacon nulls. It is best to use the times of the deepest nulls for which the satellite is at its highest elevation. Figure 3 is a plot of the 10-meter CW beacon signal from RS-12. The shape of the envelope, which resembles AM modulation, is due to Faraday fading. As you can see, the effect is quite pronounced. The interval between fades is about 5 seconds in this plot. Spaces between

the individual Morse code characters can be seen as narrow gaps in the waveform.

Computing χ and θ

The angle χ is simply 90° minus the satellite elevation angle. If α is the elevation angle of the satellite in degrees, then:

$$\chi = 90^\circ - \alpha \text{ degrees}$$

Finding angle θ is a more difficult. You may calculate angle θ with a bit of vector mathematics:

$$\theta = \frac{180^\circ}{\pi} \cdot \cos^{-1}(\hat{S} \cdot \hat{B}_o) \text{ degrees}$$

This expression involves a dot product between $\hat{S}$, a unit vector pointing from the observer to the satellite, and $\hat{B}_o$, Earth's magnetic field unit vector. You will need to calculate $\hat{S}$ based on the azimuth and elevation angles provided by the satellite tracking software. In Cartesian coordinates, unit vector $\hat{S}$ may be written as follows:

$$\hat{S} = S_x \hat{x} + S_y \hat{y} + S_z \hat{z}$$

where: $S_x = \sin \gamma \cos \delta$
 $S_y = \sin \gamma \sin \delta$
 $S_z = \cos \gamma$

and $\gamma = 90^\circ - \alpha$
 $\delta = 360^\circ - \beta$

Angles α and β are the elevation and azimuth angles of the satellite, respectively, in degrees.

In the above, we have chosen the zenith for the z direction, north for the x direction, and west for the y direction.

The direction of Earth's magnetic field vector B_o must be computed in order to solve for angle θ . Also, the magnitude of B_o is needed as an input to the TEC equation. The difficulty with specifying B_o is that its magnitude and direction vary considerably along the propagation path. In order to precisely compute TEC, one would need to take into account this variation of B_o along the entire propagation path. A simpler approach is to assume a constant magnitude and direction for B_o . It is recommended that you compute B_o at an altitude of 380 km overhead of your location (10). Although using a constant value

for $|B_o|$ and $\hat{B}_o$ is a rather crude approximation, this assumption does not introduce significant error in the TEC computation (11).

B_o may be obtained from a convenient computer program written for the PC (12). The program, originally written by researchers at NOAA, comes with the International Geomagnetic Reference Field (IGRF) model of Earth's magnetic field. After executing the program, type *igrf* when prompted for the model data file. Next, enter the date, specify geodetic coordinates, enter the altitude (380 km), and enter your latitude and longitude. The program output gives you the strength of B_o (F) in nanotesla, the magnetic dip angle (I), and the magnetic declination angle (D). The unit vector $\hat{B}_o$ may then be written as follows:

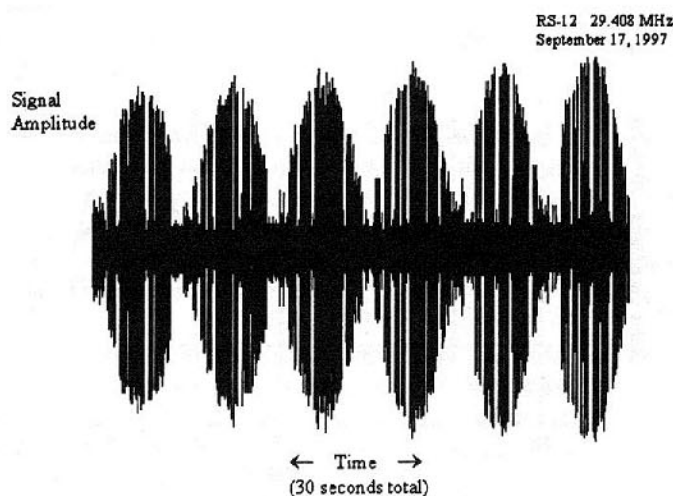
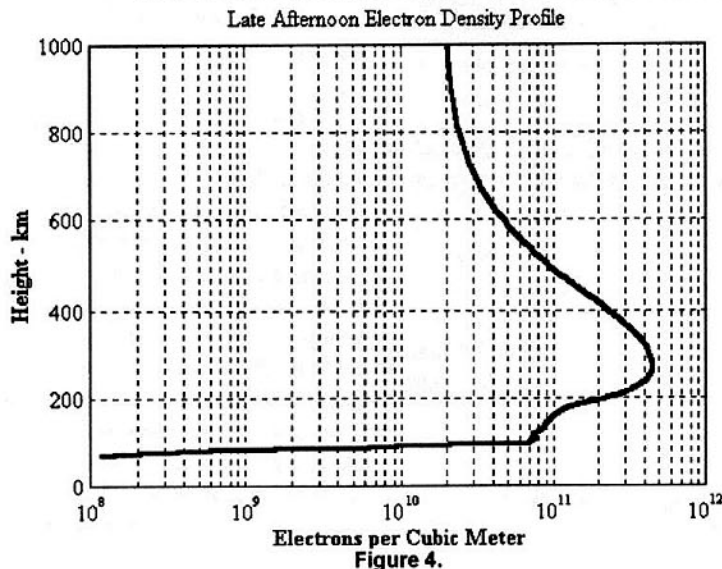
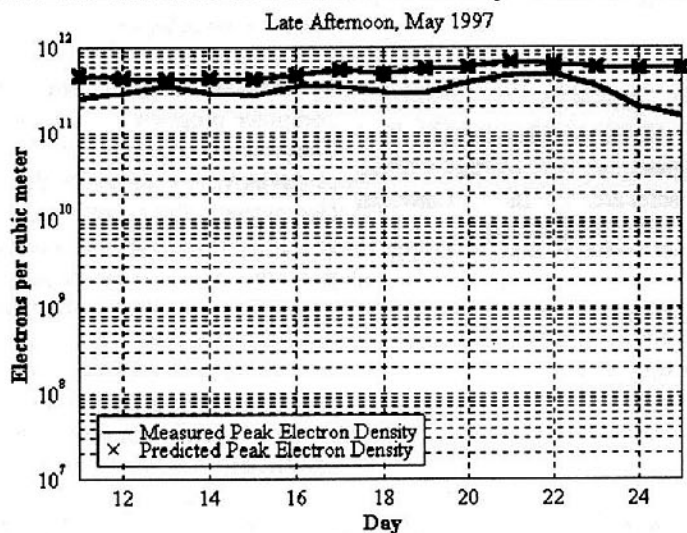


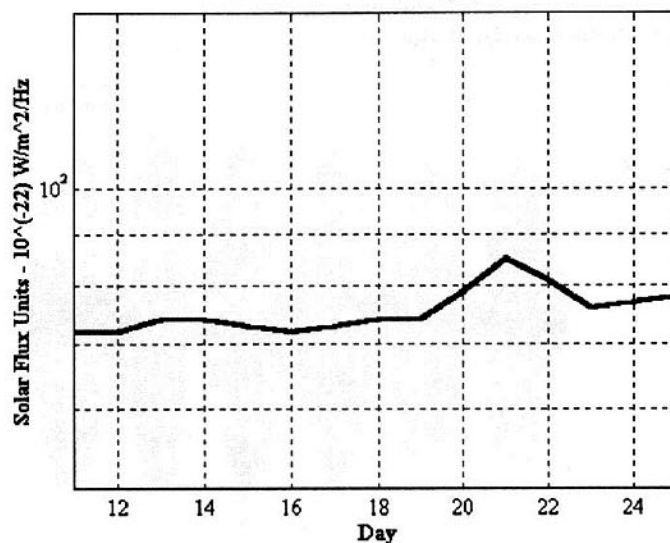
Figure 3.



Measured vs Predicted Peak Electron Density - Stanford University



Solar Flux for May 1997



$$\hat{B}_o = B_{ox} \hat{x} + B_{oy} \hat{y} + B_{oz} \hat{z}$$

where: $B_{ox} = \sin \gamma \cos \delta$
 $B_{oy} = \sin \gamma \sin \delta$
 $B_{oz} = \cos \gamma$

and $\gamma = 90^\circ + I$ degrees
 $\delta = 360^\circ - D$ degrees

Using $\hat{S}$ and $\hat{B}_o$, you can compute θ , and then substitute θ , χ , and $B_o = |\mathbf{B}_o|$ into the TEC equation to solve for TEC. Since these steps are a bit tedious, you may want to write a short computer routine to perform the calculations. We have written a short program that performs these calculations. The program runs on the PC, and is available from F. Bauregger's Web site (13). The program asks for the azimuth and elevation angles of the satellite, magnetic declination, magnetic dip angle, and magnetic field strength. The program returns a TEC value. Also included in the zipped file is a version of the program that will run in Matlab.

Validation

Once you have computed TEC, you may want to know how accurate your results are. You may compare your computed TEC value to those published by NASA's Jet Propulsion Laboratory (JPL). JPL measures the dispersion of the L1 and L2 GPS signals to determine TEC up to the height of the GPS satellites (20,000 km). The results are published in near real-time for most of North America on the Internet (14). Your TEC value will be lower than the JPL figures if you use the low altitude satellites listed in Table 1. However, since most of the ionization resides in the ionosphere below 1,000 km, your TEC figures should not be terribly low. Keep in mind that the sub-satellite point is constantly moving throughout the satellite pass. The TEC value you compute will vary depending on the density of the ionization through which the radio wave travels. For example, for a north to south pass, you will be able to observe the rather large horizontal TEC gradient which extends from Mexico to Canada during the day in North America.

Some Results

The techniques described in this article were developed for an electrical

engineering class project at Stanford University. The class is an electromagnetic wave laboratory class, in which the practical aspects of radio wave propagation and transmission line theory are taught. Our group measured the Faraday rotation of the RS-12 satellite radio beacon at 29.408 MHz for a two week period in May 1997. Each satellite pass was in the late afternoon, typically between 3 pm and 5 pm local time. Some of the results of this experiment are presented in this section. Rather than simply plot TEC, we tried to use the measured TEC values to determine other interesting features of the ionosphere. First, we developed an electron density profile as shown in Figure 4.

In order to generate this electron density profile, Faraday rotation measurements were first used to determine TEC. Then we assumed a normalized shape of the electron density profile with the help of a computer model of the ionosphere (15). Using our measured TEC value in conjunction with the integrated normalized electron density, we computed N_{max} , the peak electron density in the ionosphere. Finally, we plotted the normalized shape function, and set the peak electron concentration to N_{max} to arrive at the plot in Figure 4.

Figure 5 shows the peak electron density in the ionosphere as measured by Faraday rotation over the two week observation period. Also plotted is the peak electron density as predicted by the computer model of the ionosphere. Agreement between the two curves is good. Figure 6 is a plot of the 10.7 cm solar flux over the two week period in May (16). Since there is a linear relationship between TEC and solar flux (17), the two curves should be similarly shaped. Compare Figure 6 with the measured peak electron density depicted in Figure 5. There is a general increasing trend in the solar flux, and this is observed in our measured electron density data as well, until May 23rd. Also, the peak in solar flux on May 21st is observed simultaneously with a peak in measured electron density on May 22nd. This interesting observation is probably telling us that there is a time lag between a solar activity increase and a corresponding increase in electron density. This is reasonable since the ionization likely takes time to build up after an increase in solar activity. Notice that the measured electron density remains at a relatively high level until May 23rd, when the solar flux had already decreased to relatively nominal levels. The lag between solar activity changes and ionization

response is evident here as well. Any excess ionization created by a short term increase in solar activity will *hang around* for a while until it recombines or is removed by some other process.

Conclusion

Faraday rotation is an interesting electromagnetic phenomenon, and it is exciting to make use of Faraday rotation to make meaningful measurements of the electron content within the ionosphere. The simplicity of the measurement procedure and the required equipment makes the experiment easy and enjoyable. Understanding the theory of Faraday rotation helps one appreciate the phenomenon even more. If you would like to learn more about magneto-ionic theory and the behavior of radio waves in the ionosphere, the books by Budden and Davies are excellent. Hopefully you have learned a bit about Faraday rotation, and in the future, will not be quite so annoyed about the QSB on the Mode A downlink!

Acknowledgements

The authors would like to give thanks to Professor David B. Leeson for his encouragement, guidance, and wisdom throughout this project. We are also grateful to Professor Robert A. Helliwell for providing the initial inspiration to pursue this experiment. Thanks to your support, we have gained a greater understanding of and

appreciation for radio wave phenomena in the near-Earth environment.

Frank Bauregger and Christine Law are graduate students in electrical engineering at Stanford University. They are both research assistants in the Space, Telecommunications, and Radioscience (STAR) Laboratory.

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ESA Meeting Held

(via ANS) On January 20, 1998, Phase 3D Project Leader and AMSAT-DL President, Dr. Karl Meinzer DJ4ZC met with ESA officials in Paris to discuss the possible launch of the Phase 3D satellite on the third test flight of the Ariane 5 launch vehicle, AR-503. Dr Meinzer gave a short presentation on AMSAT, its background and the history of cooperation it has enjoyed with ARIANE for many years. He then outlined the development history of Phase 3D and expressed a strong desire for a launch on AR-503.

The ESA officials indicated willingness to consider a launch on AR-503, But made no commitments. They stated that they are also investigating the possibility of placing another payload on the mission that would preclude launching Phase 3D. Nevertheless, ESA did agree to make an initial study of the configuration that would be associated with Phase 3D, were it to be launched on AR-503 along with several other payloads. They also agreed to investigate other possible launch opportunities, including ARIANE 4s.

Another meeting is scheduled for the end of February, at which time it is hoped that more definite information will be available. Dr. Meinzer said on returning to Marburg following the 20 January meeting, "ESA is making bona-fide efforts to identify a launch for us. I think we stand a good chance." Dr. Meinzer and AMSAT-NA officials agreed that our job now is to get Phase 3D completed and tested, so that it will be ready to go if ESA gives the "green light". AMSAT-NA Executive Vice President, Keith Baker KB1SF likened this to going to the airport to *stand by* in order to get on a fully booked flight. "That strategy often pays off", he added. ■

Minutes of the AMSAT Board of Director's Meeting

Held October 19 and 20, 1997 in Toronto, Ontario, Canada

The meeting convened at 1:00 p.m. EST on Sunday, October 19, 1997 at the Delta Hotel, Toronto, Ontario, Canada. Members of the Board of Directors (BoD) in attendance were:

- Keith Baker KB1SF (Executive Vice President)
- Tom Clark W3IWI
- Dick Daniels W4PUJ
- Joe Holman AD7D
- Andy MacAllister W5ACM
- Bill Tynan W3XO (President)
- Stan Wood WA4NFY

Others participating at various times included:

- Laura Halliday VE7LDH
- Martha Saragovitz (Corporate Secretary)
- Barry Baines WD4ASW (V.P. Field Operations & Alt. Board Member)
- Frank Bauer KA3HDO (V.P. Manned Space Programs)
- Bill Burden WB1BRE (V.P. for Strategic Planning)
- Martin Davidoff K2UBC
- Ken Emandes N2WWD
- Art Feller W4ART (Treasurer)
- Randy Green KB0BVR
- Robin Haighton VE3FRH (V.P. Canadian Liaison)
- Greg Jones WD5IVD
- Phil Karn KA9Q
- Lou McFadin W5DID
- Keith Pugh W5IU (V. P. Operations)
- Eric Rosenberg W3DQ
- Dan Schultz N8FGV
- H. Paul Shuch N6TX (Exec. Dir., The SETI League)
- Ray Soifer W2RS (V.P. International Affairs)
- Russ Tillman KC5JVB (AMSAT Journal Editor)
- Bob Twiggs KE6QMD
- Jim White WD0E
- Mark Kanawati N4TPY
- Paul Williamson KB5MU (V.P. Electronic Publishing)
- Howard Ziserman WA3GOV

I. Election and Appointment of Officers

President Tynan opened the meeting and welcomed the new BoD members Holman and Wood and alternate Baines. He then asked if there were any volunteers for the office of President and stated that it is time for the group to consider selecting his successor. Clark reminded the Board that AMSAT had in the past, tried running the organization with a General Manager but that had met with mixed success. Tynan cited his opposition to having a paid President and Baker voiced the opinion that a General Manager

should be accountable to, but not a member of, the Board.

Daniels recommended that a Search Committee may be needed to find suitable candidates for the office of President. Since no one suggested a person to serve as President, Tynan reluctantly agreed to serve for another term, asserting that the matter of where AMSAT is going needs to be defined. He stated that, for example, a decision is needed on setting up a separate for-profit AMSAT organization. It was announced that the office of Vice President for Engineering had become vacant as Dick Jansson WD4FAB had said that he did not want serve in that capacity any longer. It was noted that Dick had appointed Stan Wood as his Assistant VP. Therefore, it was recommended that Wood be chosen to fill this office. All of the other present Officers indicated their willingness to serve another year. Clark made the motion that the incumbent Officers be retained, and that Stan Wood be confirmed as VP for Engineering. Baker provided a second and they plus Wood were unanimously elected to office. Tynan stated that he would appoint Burden as V.P. for Strategic Planning and reappoint the various other officers who are designated by the President and do not require Board action.

Tynan stated that, as in past BoD meetings, the 1998 budget for each department would be examined as each department report is presented. Then adoption of the final budget will be handled at the end of the meeting.

II. International and IARU Matters

Soifer reported on the IARU International Satellite Forum that had been held in conjunction with this year's AMSAT Annual Meeting. He mentioned several Forum topics of special interest to the amateur satellite community. First, the suggestion that AMSAT-NA participate in the monitoring of amateur satellite frequencies for the presence of non-amateur intruders. For example, it was suggested that we enlist some of our members in Region II to assist with this effort. Noting that this should involve members from various areas, including Canada, a motion was made by Tynan and seconded by Clark that Baker and Haighton be delegated the responsibility of working out the details with groups involved in similar activities, such as the ARRL Official Observer team, and then report at the next BoD meeting. The motion passed unanimously. Tynan then asked that Hans van de Groenendaal ZS5AKV write an article on this subject for *The AMSAT Journal* (see the Nov/Dec issue).

Soifer then suggested that AMSAT-NA write a letter to the IARU for the attention of Tom Atkins, President of Region II, making specific recommendations for additional frequencies to be allocated for amateur satellite use. For example, expanding 10 m downlink frequencies from 29.7 to 30 MHz, opening some part of the 6 meter band for satellite use worldwide and working toward having 3400 to 3410 MHz available for use in Region I. Soifer suggested that, after consulting with the ARRL, a paper specifying these recommendations be produced and then submitted to the BoD for approval. Baker seconded and the motion was passed by unanimous vote. Tynan, Soifer and Feller will prepare the document.

Atkins has suggested that AMSAT-NA send an observer to the IARU Region II conference to be held

in Caracas, Venezuela in September 1998. Clark so moved, Tynan seconded and the motion passed unanimously. Tynan urged Soifer to represent AMSAT-NA at that meeting. He indicated a willingness to attend if work commitments do not prevent it. An addition to the Department 17 of the 1998 Budget to cover travel costs to Caracas was approved by a consensus.

Hans van de Groenendaal has requested that AMSAT-NA circulate for comment from international AMSAT groups our Comments on the FASC Discussion Paper as approved by the AMSAT-NA Board and published in the September/October 1996 issue of *The AMSAT Journal*. It is noteworthy that our document included a definition of what constitutes an Amateur Radio satellite. Soifer will prepare an explanatory preamble to the Comments. Responses from abroad will be sent to van de Groenendaal who will then modify or accept the document.

The BoD then considered the Discussion Paper and Report prepared by the Future of the Amateur Service Committee (FASC) concerning a redrafting of Item S-25, Regulations Affecting the Amateur Service. Soifer has drafted a letter with the purpose of reinforcing what we interpret as the purpose in changing the language as it addresses the topic of permissible activity in the amateur bands. One member of the Committee has suggested that AMSAT-NA recommend the wording be changed to allow greater latitude by individual countries. Specifically, it would include AMSAT's proposal to broaden the permissible use of Amateur Radio to include things other than those relating to radio techniques. One suggested wording would say "National administrations shall permit their licensees to engage in any international communications that are solely with a personal aim and without pecuniary interest which the administrations consider to be proper as long as they are 1) of a personal character or, 2) incidental to the purposes of the Amateur Service". Thus, an administration could permit its licensees to engage in personal scientific or technical research of their own choosing regardless of whether the subject matter of that research is relevant to radio techniques, as long as the administration's own requirements are met.

Soifer read the entire text which included justifications for making the changes and asked if the BoD wanted to make changes or approve the document as written. Feller suggested tabling the issue saying that the present regulations can be interpreted to now permit these activities and cautioning that there is a danger in citing certain specific examples. Tynan replied that he would like to see the rules broadened so that amateur satellites may be used to transmit scientific data which may not be related specifically to radio. He emphasized that this will aid us in our desire to work with various university projects. He cited the star intensity study being proposed by the University of Toronto as but one example. Soifer pointed out that AMSAT is merely supporting a proposal that had already been made in draft form by the Committee and that there will be many steps to follow before it becomes IARU policy.

Williamson pointed out that a danger lies in that, as technology advances, more and more non-amateurs will want to use our frequencies as the easiest place to put their downlinks. Noting the current predatory environment, he stated *if the door is opened a crack, it will then fly open*. Tynan countered that, as long it is understood that amateur radio satellites are open to

all amateurs and that they will use non-proprietary codes with data available to anyone who wants to receive it; this should not be a problem. He emphasized that such provisions are key to the use of amateur frequencies, and that, researchers who insist on keeping their data secret until they can publish, would not be able to use amateur frequencies, nor would they want to.

Soifer then referred to more of the proposed wording. "Except with the authority of the relevant administration granted to meet a particular operational need, (e.g., command stations) transmissions between amateur stations shall not be encoded for purposes of obscuring their meaning." Feller stated that this is a non-issue and that this language is not needed.

The Board considered and then rejected the tabling of the issue. Clark then proposed that if the controversial paragraphs of the letter are deleted, he would make the motion that the remaining text of the letter be adopted and sent to the IARU. This was defined as the second complete paragraph on the third page (part S-25.4) of the letter. Holman seconded the motion and the Board approved the motion with Baker and Wood absent from the room. Soifer agreed to prepare and mail the revised letter.

III. Manned Space

Bauer's announcement that Amateur Radio is now an official payload on the International Space Station (ISS) was met with applause. He stated that there is lot of work to do and added that the project will need to acquire hardware. The station is to be built in stages, with the first stage a relatively simple transportable FM transceiver. Later stages will include more bands and modes. The first requirement is for Training Hardware for the first stage. It is needed by the first quarter of 1998. The schedule is very tight and first stage hardware must be in place in mid-1998. Noting that this is an international project, Bauer said that he was encouraged by the cooperation seen between various countries and pleased to have Italy join the group. Designing and assembling the permanent Amateur Radio station will be a big job. Tynan expressed concern that, for the later stages, the complexity might be too great. Bauer agreed that it was a major project and required an equivalent development effort. He said the ISS team is being beefed up to make it happen. Noting that it will be expensive, he said that he would like AMSAT to do a donation drive to provide partial funding. Tynan asked where the equipment would be fabricated and integrated? Bauer replied that the various pieces might come from a number of countries but that integration would probably take place in the U.S. Tynan expressed the thought that perhaps the Orlando facility could be used to accomplish this.

The schedule calls for planning and defining the interfaces to be done this year with completion of the project in 2002. Last year the project submitted a proposal to NASA and was granted \$42K that has now become available for development of the on-board amateur station. Some of this money has been used to support the Safety-Data packages that are needed for the transportable station. There was also an immediate need to develop a filter to fly on *Mir* to get around the problem of their commercial radio link interfering with the ham radio equipment on board. NASA funding for two more years has been requested: in 1998 it is planned to spend \$29K for purchasing hardware and qualifying it to fly both inside as well as outside a manned spacecraft. Noting that the ISS Amateur Radio station is a joint NASA-AMSAT-ARRL activity, Bauer emphasized the importance of keeping its finances separate and stated that, due to his

professional employment, he must not be associated with any fund raising activity. Tynan suggested that ARRL might better handle this, but support for a separate AMSAT campaign was also expressed. Burden stated that the ARRL is currently involved in a major (spectrum protection) fund-raising effort and that timing of an ISS campaign would be important to achieving a successful outcome. Baker suggested that AMSAT's campaign begin in 1998 but not to at the same time with an ARRL effort.

Clark emphasized the voluminous amount of paperwork that is demanded by NASA for any manned mission, e.g., just to document the software. It was agreed that this was not the type of thing volunteers want to do, so it must be done under contract. In response to a question about establishing a fund raising campaign, Bauer said that it should begin with an educational effort to acquaint hams and others what the ISS project will do. Tynan stressed the need for informative articles to be written for *The AMSAT Journal*, *QST*, etc. Saragovitz opined that persons outside of AMSAT would likely be interested and might be contributors. Ziserman reported that he had seen much interest at hamfests in the SAREX program. Clark confirmed this observation and noted the interest at NASA in projects that involve outreach and education. Bauer stated that the ISS project is a highly credible project in the educational arena. Baker asked about the planned orbital altitude of the ISS and Bauer replied that it would be similar to that of *Mir*.

Bauer stated that there are plans to get *Mir* back on the air next year. He reported that in 1998 there will likely be only one Shuttle mission carrying Amateur Radio because the flights are booked solid with other payloads. Daniels asked if we will run any classroom communications through *Mir* and Bauer replied that there were many last year until *Mir* began running into problems.

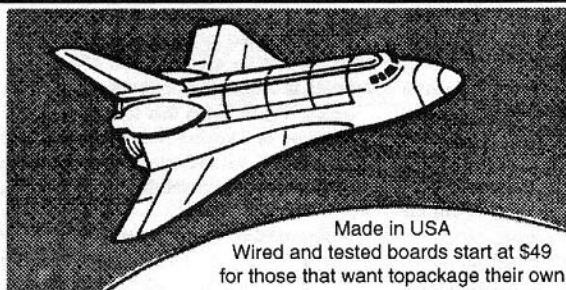
Tynan asked Bauer if the proposed budget for his department is appropriate in the light of the additional ISS activity. He responded that travel expenditures will likely double. A figure of \$14K was agreed to for Manned Space Department travel.

Noting that more help will be needed for the ISS project, Bauer said that he was looking toward developing a strong team that would include AMSAT, ARRL and NASA. Tynan suggested that Bauer write an article for the Journal introducing the project and describing its benefits, and stressing the need for volunteers to accomplish it.

With regard to frequencies, Bauer said that most of our international partners seemed satisfied with uplinks of 145.45, 145.47 and 145.49 MHz. On the other hand, a downlink of 145.80 MHz was especially requested in preference to certain others. At the recent ARRL-sponsored Digital Communication Conference Bauer asked that the Automated Packet Position Reporting (APRS) community move down from 145.79 to 144.39 MHz so as to avoid interference with the proposed 145.80 MHz satellite downlink. This new frequency would be in the recently vacated 144.30 to 144.45 MHz OSCAR sub-band. To achieve this shift downward may require a compromise wherein the APRS enthusiasts will change frequency and in return for AMSAT-NA assuring them that the ISS, Phase 3D and future digital satellites will support APRS experimentation. He said this might help to neutralize the mistaken impression that AMSAT is anti-APRS. Tynan noted that, while AMSAT-NA might support APRS users, we cannot speak for operators of non-AMSAT amateur digital satellites. Clark made the following motion. "AMSAT-NA recognizes that APRS is an exciting and vital facet of Amateur Radio and will support APRS experimentation through various Amateur Radio satellites and the ISS". Tynan

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seconded and after discussion the motion passed unanimously.

Bauer reported that there is an effort to raise funds to compensate the APRS users for their costs incurred in moving to 144.39 MHz. This might be the case for those who use crystal-controlled transmitters and receivers and possibly cavities. A donation pool has been initiated with donations from individuals and TAPR. Clark moved that AMSAT allocate an amount up to \$500 as our contribution to the APRS QSY fund to be administered by TAPR. This was seconded by Baker and the motion passed with Holman abstaining. It was stated that the fund will not officially be started until a survey has been conducted to determine what costs APRS operators will incur. Clark expressed pleasure at how this is turning out and wanted to commend Frank Bauer, Steve Dimse N4HV and Greg Jones WD5IVD for getting behind this effort.

Bauer said he anticipated that the ARRL might take a similar action and may list ISS and APRS frequencies in the Repeater Directory. Clark suggested that APRS be used in school to advantage in demonstrations involving SAREX and the ISS. Bauer noted that, at previous BoD meetings, he had described how AMSAT and the APRS community worked together to support the university-built SPRE experiment. This effort was endorsed and coordinated by NASA and achieved positive results in the area of education.

The BoD members thanked Greg Jones for his role in helping to clear 145.79 MHz and commended Bauer as well.

IV. Phase 3D Progress Report

Stan Wood introduced his report with a pledge to respect the judgment of the Board and went on to discuss status. A lengthy and detailed tutorial on the state of the Phase 3D project ensued along with considerable discussion.

Wood indicated that the structural modifications to the spacecraft were coming along well and should be completed shortly. First, he said that the structural modifications made necessary by the revised ESA launch environments, are all but complete, with only a few things left to accomplish. McFadin characterized this as about 90 to 95 percent complete. Wood and McFadin were high in their praise of the improvement in the ruggedness of the spacecraft these modifications have brought. Wood said that, while work to put the spacecraft back together is proceeding nearly as planned, a number of issues still remained to be resolved before the spacecraft could be declared *flight ready*. These included uncertainties about the possible impact of its increased mass on its ability to achieve its intended orbit, as well as spacecraft thermal balance issues.

Wood noted that the modifications, while adding mass, did not add much mass for the improvements made, about 30 kg. That brings the total to about 630 kg. He stated that this does present an apparent problem in achieving the desired orbit, but further study by those knowledgeable on that subject is certainly called for. He noted that the total weight of all the payloads is less than 50 kg, so no significant weight reduction can be obtained by leaving any of that equipment out. Several scenarios for mass reduction were discussed, but it was emphasized that a BoD meeting is not the optimum place to solve technical problems such as this. It was suggested that Ken Ermandes, who is in regular contact with Viktor Kudielka OE1VKW, inform him of the mass, so that he can look at the orbit situation. It was

noted that Karl Meinzer depends a great deal on Kudielka for orbital analysis.

Wood reported that the launch delay allowed the Phase 3D team some additional time to re-check previous calculations regarding the spacecraft's thermal balance in space. These re-calculations, made by Dick Jansson WD4FAB using a more sophisticated computer modeling technique than was used previously, have surfaced a potential issue regarding the spacecraft's thermal balance during the spinning mode following launch, but prior to solar panel deployment. Wood noted that a number of these thermal models run on the spacecraft's final design indicate that it could potentially become too cold during this period.

At this point McFadin discussed the remaining open items, including on the thermal issue. He said that to resolve this potential problem it may be necessary to install multi-layer insulation (thermal blankets) on the exterior of the spacecraft. Because this was not planned for in the original Phase 3D design, it will be necessary to design these blankets and also evaluate any effect on antenna performance. He said it may be required that the antennas be raised off the surface of the spacecraft.

Wood indicated that this issue has already been brought to the attention of Dr Karl Meinzer, the Phase 3D Project Leader. Sources and costs for the thermal insulation have already been investigated and specifications for the blankets are now being prepared. The possibility of finding an alternative solution is also being explored.

McFadin continued his report with a description of the database used to keep track of the spacecraft's 70 subsystems. He mentioned some items that required further testing and others that had been tested successfully but not yet installed. There needs to be another complete integrated systems test, a thermal vacuum test and preparations made for shipping the spacecraft.

Dr. Meinzer has said that he'd like to keep the Orlando lab open to do a burn-in test after construction and testing is complete, keeping the satellite running until launch. Tynan noted that to do this would require at least one or two full-time persons on site and that AMSAT-DL has indicated the possibility of providing partial funding to cover the associated costs.

Additional discussion centered about how and when thermal vacuum and shake tests are to be done and whether the burn-in will be done with antennas or dummy loads connected. Daniels stated that the spacecraft should not be subjected to a lateral shake test of 5g until we learn that it is required. McFadin opined that individual modules should be thermally tested before testing the assembled structure. Finally, he stated that as soon as the structural work was completed, the mechanical team should examine the new SBS and correct any deficiencies.

V. Phase 3D Finances

Baker reported on his calculations that were made as of September 30, 1997. So far, AMSAT-NA has expended \$1.396 million including our share of the launch payment made through AMSAT-DL in 1995. He reported that it's understood that AMSAT-DL will not ask for additional contributions in support of the launch unless there is a supplementary charge. Daniels stated and Baker agreed that if Phase 3D gets a ride on another mission with its own integration costs, there could be an increase in the launch expenditure.

Baker said that it's difficult to estimate what our expenses to the completion and launch of Phase 3D will be even if it is assumed to be launched in mid-1998. An estimated \$100,000 is needed for the launch campaign and a ramping down of the Orlando facility. Baker asked Wood and McFadin to provide an estimate of those expenses and Feller asked for an estimated timetable. Wood opined that these amounted to \$27,000 to \$28,000 per month and added that the recent Phase 3D structural modifications added to these costs. Baker said that a \$20,000 expenditure for thermal blankets may only be a rough estimate. Tynan reminded all that additional work is required on the SBS. Admitting that his estimate was highly presumptive, Baker said that if Phase 3D flies in 1998 the total project cost to AMSAT-NA could be somewhere between \$1.9 and 2 million. Looking back to 1991, Baker said that the amount contributed directly to AMSAT-NA for the project to date from all sources was about \$1 million. An additional \$530,000 came from the ARRL, \$76,500 from AMSAT-UK and, this year, \$50,000 was received from JAMSAT. So, the total AMSAT-NA receipts amount to \$1.625 million.

The question was then raised as to how much will be raised until completion of the project. Baker said that over the past few years, AMSAT-NA has been bringing in \$4,000 to \$5,000 per month from various sources and that trend may (or may not) continue. Much will depend on whether another fund raising campaign is held, and how successful it is. Tynan said that both AMSAT-UK and AMSAT-DL now realize that most of the current expenses for Phase 3D are now being borne by AMSAT-NA. He also reiterated that AMSAT-DL may be able provide additional financial support for those activities.

Baker summarized the AMSAT-NA funding situation to September 1997 by stating that when all Phase 3D receipts are compared with what we've spent, plus looking at the bills coming in, we're about breaking even (as of that date in mid-October). However, there are still major satellite completion, test and launch expenses yet to be faced by AMSAT-NA for Phase 3D without the prospect of substantial additional revenues coming in.

Clark counseled that the situation should be looked at as a challenge and to go out and raise funds now, pointing out to our members that difficulties such as ours are not uncommon with advanced technologies. We should tell them that if they want to see the project completed, now is the time to send a contribution.

Tynan advised doing the campaign after a successful Ariane 502 launch and before the end of 1997 for the possible tax advantage for U.S. contributors. He said that November 30 should be the target date for mailing the letter. He advised that the facts concerning the current state of affairs be made known to our members in a positive but forthright manner. Haighton offered to help draft the letter. Offering incentives in return for donations might also be considered. Baker suggested that the letter should also state that AMSAT-NA is likely to be at least \$250,000 short of being able to pay all the bills from current AMSAT-NA Phase 3D funds by the launch date.

Daniels asked how long it would take ESA to analyze the data after the launch of Ariane 502 and make a decision about the next launch. The reply stated not to expect this before the beginning of 1998. [Editor's Note: This meeting took place about ten days prior to the A-502 launch at the end of October.]

Clark made a motion that the Board re-evaluate the \$300,000 flag set up last year to indicate when AMSAT-NA spending for Phase 3D places undue strain on AMSAT-NA funds as a whole. McFadin and Wood were directed to help estimate future Phase 3D expenses, including modification of the SBS, and then the Treasurer, with the assistance of the Corporate Secretary, will inform the BoD to take appropriate action. The motion was seconded by Daniels and approved by a unanimous vote.

Further strategies for fund raising and drafting the letter of appeal were discussed at length. The letter will also stress that AMSAT now has the opportunity to instrument the International Space Station (ISS) and that effort is also going to require substantial funding. McFadin pointed out that the vehicle ultimately used for the launch will require a compatible SBS and that a redesigned mount will be required.

VI. Prospects for Post-Phase 3D Projects and the Orlando Facility

Bauer briefed the BoD on *A Low-Cost Precise Relative Ranging Experiment* that he and Clark had first proposed at Goddard and now involves Bob Twiggs at Stanford University. Two sets of six spacecraft would be connected by cords so that the satellites would fly in formation in a gravity-gradient orientation. Using GPS and knowing the precise length of the cords, the associated relative ranging could be studied. The cords would be then be broken and the spacecraft would fly in a *swarm*. Noting that both Goddard and Stanford have an interest in formation flying, for a later phase of the study the satellites will carry an on-board micropropulsion system and actually be flown in formation. Because of the cost it's been proposed that the validity of the technology should first be demonstrated using low cost satellites. What is needed is the ability to design and construct six similar spacecraft with one to serve as a leader and the others

as followers. Basic hardware development could be done as an educational-outreach project at Stanford where some funding has already been received. Twiggs emphasized, however, that Stanford is not interested in getting into the manufacturing of spacecraft and that beyond the first unit, he envisioned that the AMSAT Orlando Lab might provide the other five. Thus, a *partnership* might be formed between Stanford University and AMSAT, rather than AMSAT contracting directly with the Government. Tynan expressed a preference for this type of arrangement. He questioned also if it would not be appropriate for AMSAT to work with Stanford during the spacecraft design phase, thus facilitating our building of the remaining five. The possibility of including an Amateur Radio payload to be activated once the experimentation was complete, was also mentioned. Clark questioned whether the wide geographical separation of the participants might be contrary to keeping the cost low. Tynan responded that with current technologies like Internet, that should not be as great a factor as it once might have been. Baker expressed concern about administrative issues. Tynan cited the experiences of other groups in making such projects rewarding educational experiences and offered the opinion that it might very well fit into AMSAT's mission.

Clark summarized what Twiggs would like to do at Stanford, namely develop a spacecraft technology program that includes a laboratory and thus they would like to do this with AMSAT as a partner. Feller noted that a similar offer may be forthcoming from the University of Toronto where in return they may offer piggyback rides for AMSAT projects on their spacecraft. It was concluded that AMSAT should explore ways on which such projects might be undertaken and the options discussed. Twiggs offered the opinion that there are a number of things that AMSAT might become involved in to generate income. Other proposals to generate income were

discussed. Saragovitz stated the opinion that, if this course is to be taken, a separate organization must be set up. Baker said that that is one course being considered. Tynan noted that the several knowledgeable people are studying such a move, but the Board has not yet decided on any course of action. Feller cautioned that ways should be found to minimize liability. He agreed to follow up on some of these issues with the help of Tynan, Soifer and Saragovitz. Tynan emphasized that, in his opinion, AMSAT should not enter into any arrangements with the idea of becoming a profit making enterprise, but only to obtain revenue sufficient to finance future amateur satellite projects. Clark asked what AMSAT's next project will be and how does it fit in with this, so that a better decision can be made? Will we be helping with the ISS and do we need a physical resource like the Phase 3D Lab and its people, or will it be better to farm out the work? The possibilities range from another Microsat to a Phase 3D-type project. He opined that we are trying to solve a tactical problem without knowing what the strategy is. Tynan explained that what we are talking about is finding a way to tide ourselves over until we embark on the next project whatever it is. He said that all we are discussing are ways of keeping the options open. He added that closing the lab and scattering the people will significantly limit those options.

Haighton informed the BoD that the University of Toronto Institute for Aerospace Studies (UTIAS) appeared to be definitely interested in having AMSAT participate in the satellite project they are proposing to the Canadian government and asked if the BoD would approve his investigating how AMSAT might fit in with such a project. Tynan replied that if the inquiry is limited to gathering information without making any commitments this would be agreeable. No dissenting opinions were voiced by any BoD members.

Satellite Orbital Elements Ray Hoad, W4SQD

Satellite	AO-10	AO-27	FO-18	FO-29	RS-10/11	RS-12/13	RS-15
Catalog Number	14129	22825	20480	24278	18129	21089	23439
Epoch Time	98016.18618397	98022.20638846	98022.19339468	98022.08933720	98022.18359547	98021.74131678	98021.88038251
Element Set	528	618	31	142	448	51	281
Inclination	26.5659	98.5237	99.0735	98.5161	82.9238	82.9218	64.8139
RA of Node	106.8704	96.3083	307.8515	38.1933	76.8698	116.5755	159.2096
Eccentricity	0.6015071	0.0008863	0.0539953	0.0351671	0.0011383	0.0030657	0.0145825
Arg of Perigee	184.9775	325.6695	241.6286	338.9721	342.265	50.9321	89.7946
Mean Anomaly	163.9695	34.3911	112.9377	19.7256	17.81	309.4547	271.9685
Mean Motion	2.058794	14.27753542	12.8324148	13.52637926	13.72389174	13.74091775	11.27529544
Decay Rate	-0.00000166	0.00000002	-0.00000001	0.00000003	0.000000056	0.0000001	-0.00000039
Epoch Rev	10973	22532	37279	7071	53027	34917	12659
Satellite	RS-16	UO-11	UO-14	AO-16	DO-17	WO-18	UO-19
Catalog Number	24744	14781	20437	20439	20440	20441	20442
Epoch Time	98022.26373192	98022.00103886	98022.17848097	98022.18610257	98022.22003858	98022.22302729	98022.17246461
Element Set	140	38	338	126	129	141	136
Inclination	97.2625	97.8595	98.5033	98.5239	98.5289	98.5273	98.5298
RA of Node	288.2504	359.8005	103.9344	107.3853	108.4416	108.314	109.0609
Eccentricity	0.0008735	0.0012654	0.0010738	0.0010663	0.0010918	0.0011319	0.0011685
Arg of Perigee	34.3834	28.1197	288.9331	289.7392	288.0572	286.7524	286.5992
Mean Anomaly	325.7978	332.067	71.0679	70.2648	71.9434	73.2419	73.3909
Mean Motion	15.33481074	14.69653806	14.29994172	14.30037206	14.30181315	14.30147092	14.30265243
Decay Rate	0.00005941	0.00000169	0.00000037	0.00000019	0.00000017	0.00000077	0.00000005
Epoch Rev	4963	74339	41751	41753	41757	41757	41759
Satellite	UO-22	KO-23	KO-25	IO-26	Mir	Hubble	Phase 3D (est)
Catalog Number	21575	22077	22828	22826	16609	20580	99934
Epoch Time	98022.21777778	98022.15487764	98022.20941922	98022.22799459	98022.20678883	98022.23228189	96260.25520000
Element Set	841	730	601	614	180	40	3
Inclination	98.2726	66.0809	98.52	98.5249	51.6541	28.4671	60.0203
RA of Node	79.6786	46.7647	96.7105	96.6363	64.1326	79.7585	342.7876
Eccentricity	0.0007287	0.0003818	0.0009962	0.0009267	0.0007031	0.0014123	0.6752895
Arg of Perigee	321.5825	345.6273	309.1394	325.284	230.6272	309.9521	180.1221
Mean Anomaly	38.4842	14.4631	50.8891	34.7732	129.4099	49.9828	179.5089
Mean Motion	14.37110461	12.86306944	14.28212629	14.2786443	15.6170276	14.86590637	1.51063698
Decay Rate	0.00000025	-0.00000037	0.00000099	-0.00000007	0.00005925	0.00000529	0.0002
Epoch Rev	34194	25591	19347	22534	68122	22568	2

Tynan asked if UTIAS wants AMSAT help in completing their proposal which is due by the end of 1997. Haighton replied that they will proceed with their proposal in any event and added that what they would like from AMSAT is a favorable opinion of their proposal and a readiness to work with them while not necessarily making a financial or hardware commitment. He said that AMSAT's involvement may be limited to merely presenting ideas to the UTIAS people (consulting). In return for AMSAT's involvement, UTIAS might agree to fly an Amateur Radio package. Wood suggested that UTIAS might wish to send students to Orlando to help with the project.

Halliday, who had visited the UTIAS the previous evening, described the University's work with the Canadian Space agency involving stellar photography. The primary mission of their spacecraft which has exceptionally good optics is to do highly accurate brightness measurements on a single star to study small changes in brightness. This might, among other things, suggest the presence of planets. The project is relevant to educational outreach in that some of the data will be made available to schools. Following a further explanation of the science involved, she told how AMSAT might help build the spacecraft, creating the real data for the scientists and then providing appropriate data to the schools. Clark noted that while university faculty and students are frequently capable of building the scientific sensor instruments, they often fail to have a good grasp of overall spacecraft design and the place they frequently bog down is RF technology. This is complicated by a lack of in-house expertise and that vendors of small, high-reliability end-to-end RF systems are not common. Thus, AMSAT might provide needed help in these areas.

Tynan summarized the contact AMSAT had received earlier this year from Jim Benson who suggested that AMSAT might help his for-profit company with a space research project to build a spacecraft to fly to an asteroid. A first step had been proposed by Clark at the time in which, in return for a financial contribution to AMSAT, AMSAT people would critique the project and the proposed design. Later, we might negotiate with Benson on a more extensive role such as a possible builder of the spacecraft. This was seen as one possible way to pay for the maintaining of our facilities after Phase 3D. Clark noted that Benson had proposed a fixed-price contract which had bothered him and some other Board members. Clark also expressed concern about the scientific validity of portions of the project. It was noted that Benson appears to be going his own way, even to the point of having his company, SpaceDev, listed on the stock exchange and is actively selling shares. The consensus was that this is not an area in which AMSAT wants to be involved.

Tynan reported that another offer had been received from the Jet Propulsion Lab in the form of an inquiry involving the construction of a package that is to be a part of a Solar Sail project to be conducted in cooperation with the German Space Agency. Although it was concluded that AMSAT would likely to be capable of building the spacecraft hardware, the short time allowed for a response, and the absence of technical details, cast doubt on the sincerity of the proposition. Therefore, JPL was informed that AMSAT would not submit a proposal.

McFadin pointed out that there is a sizeable amount of equipment at the Orlando Lab. He recommended that as part of AMSAT's planning with respect to possibly closing that facility, there needs to be a plan for what is to be done with this capital equipment. He opined

that putting components and equipment in storage is not practical and he urged that we decide whether we're going to build any more fairly large satellites soon or in the years to come. Daniels shared an experience with the fallacy of using old stock parts in even an inexpensive satellite needing a multimillion dollar rocket for launch. He noted that strategic planning is a *bottom-up* exercise and advised that AMSAT management should not attempt it without involving the people who might do the building.

Tynan proposed that the Board form a committee to assist Burden in defining what the mission of AMSAT is to be. Based on their opinions the BoD will decide if they agree and how to get there. Noting the divergent ideas among Board members, Tynan stated that we need to combine the best features and come up with a statement. It was stated that the committee should have a wide latitude of things they're going to look at in the form of potential projects, finances and organizational structure. Daniels recommended involving the people who will be the organization 10 years hence. Tynan said McFadin and Wood should be on the committee because of their experience. Clark stated he would like to see Phil Karn and Jan King involved also. The question of including satellite operators as members of the group was also suggested. Clark opined that what the majority of members usually want is what they're familiar with. Baker stated that the first step is to come up with a Mission Statement, i.e., why we exist and what we want to do - probably right out of the Bylaws - and then establish a working group. Daniels offered the opinion that the Mission Statement should not be prepared by members of the Board. In the past much effort has been spent asking amateurs what they want, while some of us have been trying to see where technology can take us. Tynan noted, for example, that when AMSAT was formed, study groups were assigned to report on how various technologies might be used in amateur satellites; no mention of computers was made. This illustrates, he said how you don't necessarily know what technologies you might be using only a few years hence.

VII. Electronic Publishing

Williamson reported that it's been a good year for AMSAT's electronic publishing with no major equipment breakdowns and usage that was dramatic for an organization of our size. The number of subscribers to the mailing lists has increased. Totals for the various services are:

- AMSAT News Service: 2400
- Keplerian Elements: 4300
- AMSAT-BB: 1600

There are 114Mb available for FTP and 64Mb on the Web. In the most recent week there were about 136,000 e-mail messages carried. In the same week there were about 50,000 FTP log-ins resulting in 5000 file transfers. There were 43 fetches of Keplerian elements in AMSAT format and 48 in the NASA format. There were about 75 fetches of the plain text version of the AMSAT News Service. It is likely that many of these retrievals served more than a single user. On the Web site for one week in September we had about 20,000 hits - significantly greater than on the FTP side. The number of persons getting Keps on the Web site are only about half the number getting them by e-mail. The AMSAT News Service is popular on the Web and at least 1600 people looked at the index of downloadable material. So, we're doing a lot to get out AMSAT information.

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Automation of the facility is underway and will be done without cost to AMSAT. What is needed and how to do it is known. There is a minimum of weird and undesirable mail and that is a problem experienced by all Internet mailing lists. We have some primitive solutions in place and that's one of the reasons it has been declining. Some additional memory was purchased this year.

Tynan noted that there is \$2,000 in the present budget and Williamson stated that should be sufficient unless some new publishing projects are undertaken. For example, if it's decided to archive all previous issues of *The AMSAT Journal*, we'd have to buy new software.

Clark said that over the weekend Davidoff had again brought up the subject of documentation of old AMSAT publications and that he would like to make historical articles available on the Web and/or on a CDROM. Citing the importance of our legacy, Clark thought that we should start to make that happen. Daniels asked about the costs involved and was told that would depend on having the volunteer labor to do this and whether to load them in a format that would be simply a photographic-type image or something where the text is actually scanned. The latter would be preferable, as it permits linking items. But, it takes more work. Baker added that the next-best thing would be to have an electronic indexing capability on the Web and that's there now. It was noted that Davidoff and Saragovitz have a copy of each past AMSAT Newsletter or Journal. Clark noted that TAPR and ARRL have embarked on similar projects so we should see if our efforts could be coordinated. The techniques involved were discussed and Clark was selected to form a committee to begin work. He will be assisted by Holman as technical consultant, Feller and Tillman.

Holman offered to find someone to do the scan and get the CD ROM made. Although not needed immediately, funding will come from the Electronic Publishing budget. Williamson questioned whether we have the rights to republish and stated that we should get a legal opinion before contacting the authors. Tynan added that just because AMSAT has the copyright it doesn't mean we have the right to publish again. Saragovitz called attention to the statement in the Journal saying that articles can be reprinted only with the permission of the authors. Holman asked if we need to make a CD ROM, publish on the Web or do both. Tynan offered the opinion that a CD is handier to use.

McFadin asked if there is a limited access Web site that could be used to archive all the Phase 3D drawings and design information? These would then be available as a back-up for the lab and would be a place where authorized members of the team can get them. Williamson said that this would not be a problem, but if needed immediately it would be necessary to spend a little money. He added that gigabytes are very inexpensive now and it is primarily a matter of getting set up, and that's not much of a problem either. McFadin will collaborate with Williamson to pursue this project.

It was suggested by Tynan that Williamson set up a mailing list of Universities and other groups interested in building small satellites. Williamson agreed to do so. It was proposed that AMSAT could help facilitate the interchange of information with a special distribution list for those seriously involved to have a place to talk together. This would be advertised in a limited way and AMSAT people could use the facility to provide advice at little cost. Clark mentioned that the Surrey Web site has a good inventory of small

satellite projects and that the AMSAT Web site has pointers to it. Tynan said that the mailing list would assist in keeping AMSAT in the forefront as a provider of help. Daniels cautioned that we must present ourselves as being aware of what is current or we'll appear to be out of step.

VIII. The AMSAT Journal

Editor Russ Tillman reported that the Journal is doing well with a good stream of articles coming in. Daniels asked about the number of construction articles, noting that AMSAT-DL's journal frequently has such material. He suggested that some might be translated and reprinted. Tillman mentioned that John Bubbers W1GYD has been providing German-English translation service for the Journal and could help respond to this request. Tynan agreed that our technical content should be upgraded and that AMSAT-DL might be a good source for such material. Other sources for technical articles were discussed.

Tillman asked if the cost of a special Phase 3D issue to be published after the launch would be included in the 1988 budget? It was agreed that it will be. Ways of reducing the costs of publishing were considered in light of the decrease in advertising revenue. Clark asked if the number of pages per issue should be reduced. Saragovitz commented that the printing cost is only about 67 cents per issue so reducing the number pages would not save much. Various alternatives were mentioned but none gained much favor.

Tynan then introduced an offer made by Grove Enterprises to absorb our Journal editorial content into their publication, *Satellite Times*. This would relieve AMSAT of the problems of printing and distribution and also offer the advantage of having our material available on newsstands. Among the disadvantages cited are that we would lose much control of the process; and AMSAT would have to purchase a subscription to *Satellite Times* for each of our members, although at a reduced rate. The proposal made by Grove put this rate at 80 percent of the regular subscription price which is about \$20 per year. However, the Grove letter said that that figure is negotiable and might be as low as 50 percent. It was noted that our members would, thus, be paying their AMSAT dues, which are in excess of what they would be able to get the same magazine for, directly from Grove. Also, AMSAT authors would be required to meet Grove's standards of composition, and sign over the rights to their manuscripts. However, they would be paid for their articles, which they are not now. Tynan noted that even at the low figure of 50 percent of the *Satellite Times* subscription price, AMSAT would be paying Grove \$10 per member per year, or about \$60,000 at the current membership. He stated that the current expense budget for the Journal is \$55,000 and we expect to take in about \$10,000 in advertising. Therefore, he concluded, the net cost for us to produce the Journal is about \$45,000 per year. Therefore, even at the low end of the Grove offer, the cost would be \$15,000 more than our current cost for producing the Journal.

Clark suggested that, if we want to affiliate with another organization we should consider one with which we already have a similar ethic, rather than with a commercial enterprise. He offered QEX, published by ARRL and the *TAPR Status Register* published by TAPR as prime examples.

Baker made a motion that AMSAT reject the Grove offer and that the President should write them a letter thanking them for their offer but stating that the Board had decided not to accept it.

Clark seconded and the motion passed unanimously.

IX. 1998 Annual Meeting

Tillman proposed, as he had the previous year, that the 1998 AMSAT Annual Meeting and Space Symposium be held in Vicksburg, Mississippi. He noted that Vicksburg is located halfway between New Orleans and Memphis on the Mississippi River and halfway between Atlanta and Dallas on Interstate Route 20. When asked about air service he said that it is one hour by shuttle bus from the Jackson, MS airport which is served by most major U.S. airlines. He said that until the advent of riverboat gambling, the US Army Corps of Engineers had been the major employer and that tours can be arranged to the Corps' laboratory facilities as well as the Vicksburg National Military Park and other historic nearby Civil War sites. The Ameristar Hotel now nearing completion promises to be a suitable location to hold our meeting and is suitable for families. Local support has been offered by the Jackson and Vicksburg Amateur Radio clubs.

Clark expressed concern that the lack of a big city location might discourage some members from attending. He noted, however, that no offers have come forward from other sites. He suggested an alternate approach might be to join forces with TAPR to hold a combined meeting, noting that TAPR and AMSAT have many overlapping interests and that a joint meeting would likely be beneficial. Saragovitz stated that, if TAPR should choose a city that has no known AMSAT group willing to help with arrangements, it probably wouldn't work out. The thought was expressed that, with only a year for planning and that TAPR had not yet been consulted on the idea, it would appear premature to make any such decision. Tynan conceded that the suggestion had value, but noted that AMSAT frequently has more good papers submitted than can properly be accommodated in the time afforded by a two day meeting. So, combining the meetings would only make that situation worse.

Following additional discussion, Tynan stressed the need for a decision to be made at the present BoD meeting. He then moved that the BoD accept the offer of the Vicksburg group to host the 1998 AMSAT meeting with a determination of the date to be made by Tillman and his group. Baker seconded and the motion was approved by unanimous vote.

X. Operations Report

Keith Pugh noted that the past year has been relatively uneventful for his department. The issues that arose and resolved included the scheduling of AMSAT nets and telephone expenses incurred by the Houston net. He had no problem with his budget. Stacy Mills has been primarily watching AO-10 and operating a related Web site. Jim White reported that PACSAT (AO-16) continues to run reliably after 8 years and noted it has been lightly used, LUSAT (LU-19) is operating satisfactorily and WEBERSAT (WO-18) is back on the air after experiencing a problem with its watchdog timer. It's expected that WEBERSAT and DOVE will experience recurring problems related to their watchdog hardware and they will require reloading instructions. Carrier suppression problems in their transmitters will limit their lifetimes and Phil Karn has offered a software fix that may be helpful. Two command team members that had moved, are back in action. The present members will be part of the Phase 3D RUDAK command team and are doing advance planning to develop strategies to control the many systems on Phase 3D. This, and other operational issues were discussed at length.

XI. Field Operations Report

Baines summarized accomplishments in 1997 and listed goals for 1998. The Field Operations organization remains strong with 155 Area Coordinators, all having e-mail capability. Representation has increased in Canada and some U.S. states while there are still geographical gaps including Los Angeles, Wyoming and New York. The Area Coordinators are listed at the AMSAT Web site and on a printed handout. Electronic mail is the primary means of keeping the Field Ops Team updated on happenings. Presentation materials for talks and hamfests are now available on the AMSAT Web site.

Development of printed and video resources also continues with the new publication *Working the EasySats* very popular. Other new publications include the updated Resource Guide and the new *Preliminary Guide to Phase 3D* that were first distributed at the Dayton Hamvention. The Dayton event was very successful and Baines also said that he was a banquet speaker at the ARRL National Convention in Jacksonville. Forty hamfests were covered by Field Ops personnel and demonstrations of AO-27 operation were provided at some of these. Three Satellite Workshops were presented in conjunction with ARRL. All were well attended with a strong response from the audience. The team did well in encouraging a greater awareness of AMSAT.

Baines stated that the goals for 1998 include recruiting more Area Coordinators, especially to fill the geographic gaps. New member support services will be enhanced, as well as the availability of materials on the Web site. The Field Ops Update printed in the Journal and the Field Ops Newsletter will be continued. A challenging task in 1998 will be to distribute information about Phase 3D including a revised Phase 3D Guide. A Satellite Workshop has already been scheduled at the Orlando Hamvention in February 1998.

When asked about the adequacy of his budget Baines replied that it was satisfactory other than for the possibility of needing extra travel funds to give symposia and presentations at meetings. It was noted that all revenue collected at the satellite workshops go to the ARRL. Tynan noted that the League has just provided AMSAT with \$500 for further educational activities.

XII. Small Satellite Conference

Tynan gave a report of his attendance at this year's Small Satellite Conference, held at Logan, Utah. He said that he had prepared a brochure highlighting AMSAT's capabilities, particularly featuring Phase 3D and some of our other activities. This he provided to a number of attendees who might be interested in utilizing AMSAT facilities and expertise. Noting that Daniels has attended these meetings in the past, Tynan considered the meeting as a valuable experience and an opportunity for others to become aware of AMSAT. Daniels said that in the past AMSAT has presented papers or poster sessions and that we ought to endeavor to give some of our more technical presentations at future conferences. Tynan stated that there were several favorable references to AMSAT at this year's meeting. He said that there will be a similar professional conference held next August at the same location and agreed that AMSAT should be there with a presentation. After the meeting, Tynan said he visited Weber State University and noticed the backup Phase 3D spaceframe on display, as well as seeing the WEBERSAT control station. He attended a

presentation on Weber's past accomplishments and current projects, and spoke briefly about Phase 3D.

XIII. Executive Session

The Board went into a closed session to deal with administrative matters including Martha Saragovitz's performance review and compensation. No record was made of the proceedings except to note that Martha will be granted an increase in pay as a result of continuing good performance and in recognition of an increase in the cost of living.

XIV. 1998 Budget

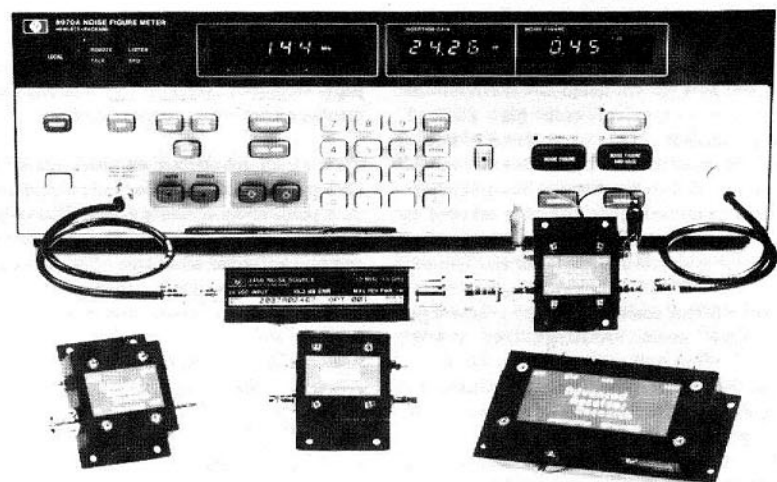
Tynan presented the proposed 1998 Budget, beginning with the income side. Noting that no significant increase in the number of new members appears likely soon, and that our membership of approximately 6000 includes 2000 Life Members, it was declared that income from yearly dues are presently insufficient to

cover the costs of providing membership services. It was suggested that each AMSAT member be asked to recruit another member and thus increase the dues income. Talk of what brings in and keeps members followed. Other present and future sources of income were discussed, including donations received for software, production of an AMSAT CDROM, proceeds from the distribution of publications and Annual Meetings and Symposia. It was recommended that dues not be increased at this time.

An estimated over-all deficit of \$268,000 is projected for 1998. This includes \$230,000 for Phase 3D, specifically the launch campaign, subcontracts, travel, rent and administrative expenses at the Orlando facility.

Feller presented the audited financial statement for 1996 prepared by the accounting firm of Verkouteren, Auerbach, Olsen and Co., recommended its approval, and that the same firm be retained for the coming year.

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P50VDG	50-54	<0.5	24	+12	GaAsFET	\$79.95
P144VD	144-148	<1.5	15	0	DGFET	\$29.95
P144VDA	144-148	<1.0	15	0	DGFET	\$37.95
P144VDG	144-148	<0.5	24	+12	GaAsFET	\$79.95
P220VD	220-225	<1.8	15	0	DGFET	\$29.95
P220VDA	220-225	<1.2	15	0	DGFET	\$37.95
P220VDG	220-225	<0.5	20	+12	GaAsFET	\$79.95
P432VD	420-450	<1.8	15	-20	Bipolar	\$32.95
P432VDA	420-450	<1.1	17	-20	Bipolar	\$49.95
P432VDG	420-450	<0.5	16	+12	GaAsFET	\$79.95
Inline (rf switched)						
SP28VD	28-30	<1.2	15	0	DGFET	\$59.95
SP50VD	50-54	<1.4	15	0	DGFET	\$59.95
SP50VDG	50-54	<0.55	24	+12	GaAsFET	\$109.95
SP144VD	144-148	<1.6	15	0	DGFET	\$59.95
SP144VDA	144-148	<1.1	15	0	DGFET	\$67.95
SP144VDG	144-148	<0.55	24	+12	GaAsFET	\$109.95
SP220VD	220-225	<1.9	15	0	DGFET	\$59.95
SP220VDA	220-225	<1.3	15	0	DGFET	\$67.95
SP220VDG	220-225	<0.55	20	+12	GaAsFET	\$109.95
SP432VD	420-450	<1.9	15	-20	Bipolar	\$62.95
SP432VDA	420-450	<1.2	17	-20	Bipolar	\$79.95
SP432VDG	420-450	<0.55	16	+12	GaAsFET	\$109.95

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Clark so moved, Baker seconded and the motion passed unanimously. Feller noted that the Management Letter accompanying the auditor's report recommended some improvements. First, that items purchased for the Phase 3D lab be bought in AMSAT's name, not that of the person placing the order. McFadin has been advised of this need. It was noted that, sometimes corners had to be cut in order to obtain components and services in a timely manner. Second, AMSAT's investment strategy was criticized. Although the Treasurer explained to the accountants that we don't know how long we expect to hold our funds before the money is needed to meet expenses and thus the investments were in low-risk Certificates of Deposit to keep us ahead of inflation. Tynan said that the accountants had been advised of the need for liquidity, but that the statement remained in the Management Letter. Saragovitz stated that Soifer has provided valuable advice on financial matters and noted that his advice has proven sound.

Treasurer Feller expressed concern about proposed Department 18 (Orlando Facility) in the proposed Budget, specifically the \$150,000 of income shown from unspecified activity. Tynan said that this figure was arrived at so as to balance the expenses of running the Orlando facility, following completion of Phase 3D, and he enumerated those expenses as presented in the budget. Possible sources of such revenue, as have been discussed previously were re-enumerated, including prospects of providing consultant and satellite construction services for commercial and academic organizations. It was urged that more information and planning are needed before a decision can be made to pursue these endeavors. Tynan made it clear that this portion of the budget depends on finding a source of the income and stressed that this Department has nothing to do with Phase 3D. Instead, it is an estimate of what is needed to engage in a profit-making enterprise in an effort to keep the Orlando facility open following completion of Phase 3D. He acknowledged that if we don't get a source of revenue, the Phase 3D lab must be closed once we're through with Phase 3D, and the proposed Department 18 would go away. Feller replied that nothing has been established in this arena, that our engaging in such activity is only speculation now and thus, not proper to include in the proposed budget. Tynan responded that any budget is a forecast and is never absolute. Daniels suggested listing this as a special, unresolved category.

After more discussion, Clark made the motion that the budgets for Departments 0 through 17 be as presented and amended in previous discussions at this meeting, with the deletion from the budget of Department 18. Wood provided a second and there were 5 votes in favor, Tynan voted no, with Baker abstaining.

XV. Miscellaneous Items

Tynan reviewed the procedures required to nominate and elect Board members and then proposed an Amendment to the Bylaws at the end of Article 3, Section 2. The addition would read as follows: "If the number of such nominations does not exceed the number of seats being contested, then the candidates so nominated shall be declared elected. If the number of such nominations does exceed the number of seats being contested, then the Secretary shall conduct an election as provided in Sections 3 and 4 hereof". Saragovitz noted that this Amendment is aimed at saving money when there is no need to hold an election. She said that the cost of conducting an election is approximately \$4,000. She recommended that the proposed change be made. It was noted that the League has a similar procedure. Clark moved to accept the motion, MacAllister seconded and it was accepted

by a unanimous vote. It was noted that this being a By-Laws change, it becomes effective 30 days after being published in *The AMSAT Journal*, if fewer than 10 percent of the membership file written objections.

Tynan then recommended to the Board that Perry Klein W3PK be named as *Founding President Emeritus*. He noted that Clark is also a President Emeritus. Daniels so moved and Baker provided a second. The motion passed with all in favor.

Saragovitz brought up the matter of the \$15 per day food reimbursement for those travelling on AMSAT business and stated that an inequity exists wherein Board members coming from out-of-town to a meeting, receive this reimbursement, while those from the local area do not. This is evident when BoD members have meals together while at meetings. McFadin offered the opinion that contractors should not be limited to the same amount as AMSAT volunteers. Tynan vehemently disagreed. After some discussion as to an appropriate level of reimbursement for meals, a new figure of \$25 per day for everyone, was arrived at. McFadin expressed agreement with this arrangement, and agreement concerning the inequity raised by Saragovitz was apparent. Wood then moved that, effective January 1, 1998 a maximum food allowance of \$25 per day be established for all those travelling on AMSAT business, or taking meals with other AMSAT volunteers, employees or contractors who are on travel, while attending meetings or participating in other AMSAT activities. Baker seconded, Daniels voted no and Clark abstained so the motion passed. Tynan asserted that, as defined in earlier BoD actions on this subject, the special provision, allowing the President to grant exceptions, in hardship cases such as foreign travel, remains in effect.

XVI. "Atta-boys" and "Atta-girls"

The following persons were recognized for their contributions.

- The volunteers who put together the Toronto Annual Meeting. Especially noteworthy was the high quality of the program and the speakers.
- Steve Dimse N4HV and Greg Jones WD5IVD for their efforts in coordinating a solution to the problem of moving APRS activity to another frequency in the 2 meter band.
- The team of contract employees and volunteers working long hours on our behalf at the Orlando Phase 3D facility.
- Paul Williamson who helped with the survey of Web Users.
- Bob Carpenter W3OTC and Bill Hook W3QBC who as volunteers assist at the Silver Spring Maryland AMSAT headquarters. Bill Hook is also commended for his excellent job of transcribing the tapes containing BoD meeting proceedings, including this one.
- Martha Saragovitz for her perseverance and all she does for AMSAT, and to Daisy, *The Official AMSAT Mascot*.

XVII. Adjournment

The meeting concluded at 3:15 p.m. EST on Monday, October 20, 1997. Other items are to be handled by e-mail or at a special meeting as the need arises. ■

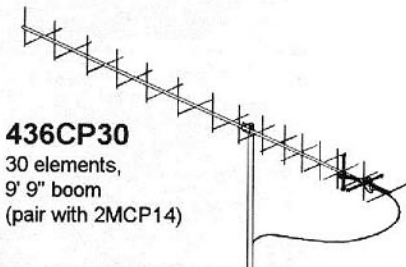
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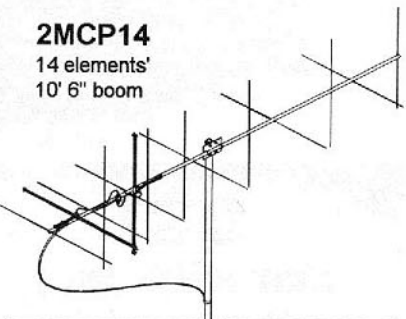
436CP42-U/G

42 elements,
18' 10" tapered boom
(pair with 2MCP22)



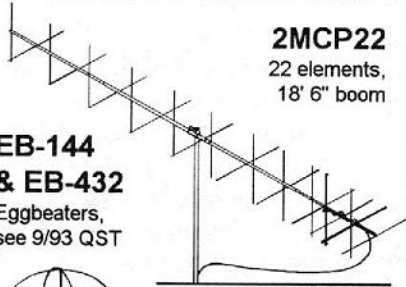
436CP30

30 elements,
9' 9" boom
(pair with 2MCP14)



2MCP14

14 elements'
10' 6" boom

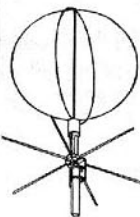


2MCP22

22 elements,
18' 6" boom

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— QST Magazine, March 1997
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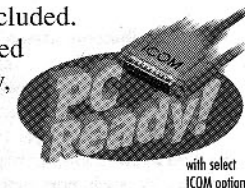
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